CROSS LAYER OPTIMIZATION FOR PROTOCOLS IN MOBILE ADHOC NETWORKS

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CERTIFICATE

Certified that **ANITA YADAV** (enrollment no. Ph. D./08/CSE/640) has carried out the research work presented in this thesis entitled **"CROSS LAYER OPTIMIZATION FOR PROTOCOLS IN MOBILE ADHOC NETWORKS"** for the award of **Doctor of Philosophy** from Dr. A. P. J. Abdul Kalam Technical University, Lucknow (formerly Uttar Pradesh Technical University, Lucknow) under our supervision. The thesis embodies results of original work and studies are carried out by the student herself and the content of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

Advances in wireless technology and hand-held computing devices have brought revolution in the area of mobile communication. The increasing mobility of humans across the globe generated demand for infrastructure-less and quickly deployable mobile networks. Such networks are referred to as Mobile Adhoc Networks (MANET). Usually, nodes in a MANET also act as a router while being is free to roam while communicating each others. Adhoc networks are suited for use in situations where infrastructure is unavailable or to deploy one is not cost effective.

Frequent changes in network topology due to mobility and limited battery power of the mobile devices are the key challenges in the adhoc networks. The depletion of power source may cause early unavailability of nodes and thus links in the network. The mobility of nodes will also causes frequent routes breaks and adversely affects the required performance for the applications.

Availability of a route in future mainly depends on the availability of links between the nodes forming the route. Therefore, it is important to predict the future availability of a link that is currently available. We have proposed an analytical model for link prediction using Newton divided difference method. This link availability algorithm is incorporated in AODV routing algorithm (AODVLP) to evaluate the performance of AODV routing protocol using the metrics viz. delivery rate, average end-to-end delay, average RTS collisions per node and route failure. In the existing AODV protocol, packets are routed until a link in the existing path fails. This results in degradation of quality of service of network in terms of end-to-end delay and delivery ratio. In this thesis, we have modified AODV routing protocol by incorporating link prediction algorithm using proposed link prediction model. This algorithm predicts the link availability time and even before the link breaks; either it repairs the route locally or send information to

the source nodes to enable them initiating a new route search well in time. This algorithm improves the quality of service of the network. Simulation results show that AODV routing algorithm with link availability model performs better than the existing AODV.

In adhoc networks, MAC protocols are responsible for the coordinated access from the active nodes. Various MAC protocols with different objectives have been proposed for adhoc networks. Maximizing the nodes' lifetime and thus the network lifetime is a common objective of adhoc networks. Since the adhoc nodes are assumed to be dead when they are out of battery, it is imperative to optimize the battery consumption at the nodes.

Another main objective is increase the capacity of the networks. We have proposed dynamic power control wireless adhoc MAC protocol (DPCP) based on modification to RTS-CTS-DATA-ACK handshake in context to IEEE 802.11 and have shown that the proposed scheme saves energy and increases throughput as compared to IEEE 802.11b std.

Several researches have proposed cross layer interactions at various layers with different objectives. However, we have proposed a cross layer design for power control and link availability (DPCPLP) in mobile adhoc networks to address both the issues of availability of links due to mobility and of increase of the battery life of the nodes. This method uses interaction of non adjacent layers e.g. physical and network layers for prediction of links break and optimization of power at MAC layer. The received signal strength and transmit power of the packets are used as cross layer interaction parameters. The proposed method performs better than IEEE 802.11 and AODVLP in terms of increased throughput, better packet delivery ratio and decreased average communication interruption time, less routing overheads, less end-to-end delay and lower energy consumption. The performance evaluation of proposed protocols is conducted using ns-2 network simulator. All the simulation results show that the proposed protocols perform better than the other protocols.

Dedicated

To

My Maa & Papa

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Anita Yadav

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LIST OF ABBREVIATIONS

MANET	Mobile Adhoc Network
AODV	Adhoc On-demand Distance Vector Routing
AQR	Asynchronous Quality of Service Routing
BR	Bandwidth Routing Protocol
CBR	Constant Bit Rate
CEDAR	Core Extraction Distributed Adhoc Routing
DSDV	Destination Sequenced Distance Vector Routing
DSR	Dynamic Source Routing
GPS	Global Positioning System
MAC	Medium Access Control
OLMQR	On-demand Link-state Multipath QoS Routing
OQR	On-demand Quality of Service Routing
PLBQR	Predictive Location-Based QoS Routing
PRTMAC	Proactive Real-Time MAC
SWAN	Stateless Wireless Adhoc Network
TBP	Ticket Based QoS Routing
TCP	Transmission Control Protocol
PCM	Power Control Medium Access Control
DPCP	Dynamic Power Control Protocol
AODVLP	Adhoc On-demand Distance Vector Routing with Link Prediction
DPCPLP	Dynamic Power Control Protocol with Link Prediction
IFS	Inter Frame Space
SIFS	Shorter Inter Frame Space

DIFS	Differentiated Inter Frame Space
EIFS	Enhanced Inter Frame Space
NAV	Network Allocation Vector
CW	Contention Window
RTS	Request To Send
CTS	Clear To Send
ACK	Acknowledgement

CHAPTER 1

Introduction

1.1 Mobile Adhoc Networks

Historically, Mobile Adhoc Networks (MANETs) have been primarily used in tactical network-related applications to improve battlefield communications. Early adhoc network can be traced back to DARPA Packet Radio Network Project (PRNET) in 1970s. The PRNET project used ALOHA [1] and subsequently used CSMA approaches to support the dynamic sharing of the radio resources, and featured multi-hop communication among nodes by introducing several distance vector routing protocols. In the early 1990, the U.S. Department of Defense continued to support research programs such as Global Mobile Information Systems (GLOMO) and the Near-Term Digital Radio program (NTDR).

The recent advances in miniaturization, and the proposal of open standards (Bluetooth, IEEE 802.11, RFID) for wireless communication, have greatly facilitated the deployment of adhoc networks and support for more advanced functions. This allows a node to act as a wireless terminal as well as a repeater and still be compact enough to be mobile. A self organizing adaptive collection of such devices connected with wireless links is said to be an Adhoc network. A wireless network is normally a decentralized network. The network is adhoc because each node is willing to forward data for other nodes, and so the determination of which nodes forward data is made dynamically. This is in contrast to wired networks in which routers perform the task of routing. It is also in contrast to managed (infrastructure) wireless networks, in which a special node known as an Access point manages communication among other nodes.

Since the adhoc network is a decentralized network it should detect any new nodes automatically and induct them seamlessly. Conversely, if any node moves out of the network, the remaining nodes should automatically reconfigure themselves to adjust to the new scenario. If nodes are mobile, the network is termed as a MANET (Mobile Adhoc NETwork). The Internet Engineering Task force (IETF) has setup a working group named MANET for developing standards for these networks.

Typically there are two types of architectures in adhoc networks: flat and hierarchical [2, 3]. Each node in an adhoc network is equipped with a transceiver, an antenna and a power source. The characteristics of these nodes can vary widely in terms of size, processing ability, transmission range and battery power. Some nodes can act as servers, others as clients and few others may be flexible enough to act as both depending on the situation. In certain cases, each node may need to act as router in order to convey information from one node to another [4].

The decentralized nature of the Adhoc wireless networks makes them suitable for variety of applications where the central nodes cannot be relied upon. It also improves the scalability of wireless Adhoc networks as compared to wireless managed networks. Also Adhoc networks have the ability to easily integrate with the existing infrastructure oriented network thereby increasing the scope of their applications [3, 5]. Some of the applications are given as follows:

a) When a disaster occurs, it is possible that existing communication infrastructure might fail completely and restoring communication quickly is crucial. In such situation, an adhoc wireless network featuring wideband capabilities can be used to provide crisis management services. By using a mobile adhoc network, a communication infrastructure could be setup in hours instead of weeks.

b) Wireless adhoc networks have applications in vehicular technology and are called Vehicular Adhoc Wireless networks. In these networks, vehicles communicate with each other and possibly with roadside infrastructure. A long list of applications varying from transit safety to driver assistance and internet access can be provided to users through these.

c) In battlefields, there is no possibility of having infrastructure oriented network. An adhoc network can be easily deployed in such areas and help in proper coordination amongst the soldiers.

d) Adhoc network can be used during travel for household applications, in telemedicine, for virtual navigation, etc.

1.2 Important Issues

There are several important issues in adhoc wireless networks. Most adhoc wireless network applications use industrial, scientific and Medical (ISM) band that is free from licensing formalities. Since wireless is a tightly controlled medium, it has limited channel bandwidth that is typically much less than that of wired networks. Besides, the wireless medium is inherently error prone. Even though a radio may have sufficient channel bandwidth, factors such as multiple-access, signal fading, noise and interference can cause significant throughput loss in the wireless networks. Since wireless nodes may be mobile, the network topology can change frequently without any predictable pattern. Usually the links between nodes are bi-directional, but there may be cases when differences in transmission power give rise to unidirectional links, which necessitate special treatment of the medium Access control (MAC) protocols. Adhoc network nodes must conserve energy as they mostly rely on batteries as their power source. The security issues should be considered in the overall network design, as it is relatively easy to eavesdrop on wireless transmission. Routing protocols require information about the current topology, so that a route from a source to destination may always be found, if possilble. However, the existing routing schemes, such as distance vector and link state based protocols, lead to poor route convergence and low throughput for the dynamic topologies. Therefore a new set of routing schemes such as Destination Sequenced Distance Vector (DSDV) [6], Dynamic source routing (DSR) [7], Adhoc On-Demand Distance Vector routing (AODV) [8] and Temporally Ordered Routing Algorithm (TORA) [9] have been developed.

MAC layer is also referred as a sub layer of the ‘Data Link layer”. It involves functions and procedures necessary to transfer data between two or more nodes in a network. It is the responsibility of the MAC layer to perform error detection for the anomalies occurring in the physical layer. The layer performs specific activities for framing, physical addressing, flow control and error control. It is responsible for resolving conflicts among different nodes for channel access. Since the MAC layer has a direct bearing on how reliably and efficiently data can be transmitted between two nodes along the routing path in the network, it affects the Quality of Service (QoS) in the network. The design of MAC protocol should also address issues caused by mobility of nodes and unreliable time varying channels.

1.3 MAC Protocols

The MAC protocols developed for wired networks like Carrier Sense Multiple Access and its variations such as CSMA with Collision Detection (CSMA/CD) cannot be directly used in wireless networks. In CSMA based schemes, the transmitting node first senses the medium to check whether it is idle or busy. The node defers its own transmission to prevent a collision with the existing signal, if the medium is sensed busy. Otherwise, the node begins to transmit its data while continuing to sense the medium. But in the wireless networks, the collisions occur at the receiving node. Since, signal strength in the wireless medium fades away in the proportion to the square of the distance from the transmitter, the presence of the signal at the receiver node may not be clearly detected at the other sending terminals, if they are out of range.

As shown in the figure 1.1, node B is within the range of nodes A and C, but C is not in the range of A. Let us consider the case where A is transmitting to node B. Node C, being out of A's range, cannot detect carrier and may send data to B, thus causing a collision at B. This is referred to as the 'hidden terminal problem', as nodes A and C are hidden from each other [10, 11].

Let us consider another problem which we face in wireless networks. In this case, node B is transmitting to node A. Since C is within B's range, it senses carrier and decides to defer its own transmission. However this is unnecessary because there is no way C's transmission can cause any collision at receiver A. This is referred as the 'exposed terminal problem', since B being exposed to C caused the later to needlessly defer its transmission [11].

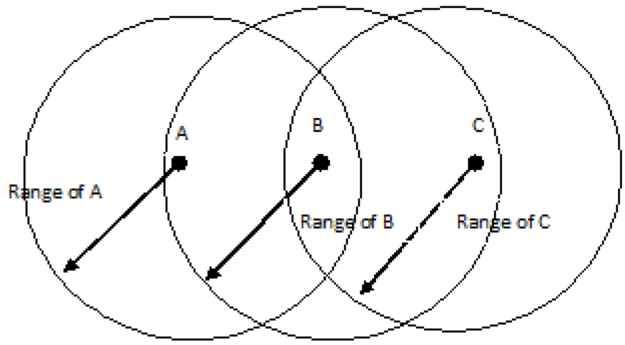

Figure 1.1: Hidden and exposed terminal problem

Apart from above mentioned problems, adhoc wireless networks have another limitation of having limited energy or battery life. This problem is quite severe because once the battery of the node is exhausted; it cannot transmit as well as receive any data. It becomes dead and this affects the network connectivity since in the adhoc network when an intermediate node dies off, the whole link has to be formed again. This leads to large amount of delay thereby hampering the throughput of the whole system. Hence the power control is a very important aspect in Wireless Adhoc network.

There are various types of MAC protocols developed for wireless adhoc networks; they are classified as shown in the figure 1.2. In contention free MAC schemes (e.g. TDMA, FDMA, CDMA), certain assignments are used to avoid contentions [3]. Contention based schemes on the other hand, are aware of the risk of collisions of transmitted data. Since contention free MAC schemes are more applicable to networks with centralized control, we shall focus on contention based MAC schemes in this thesis.

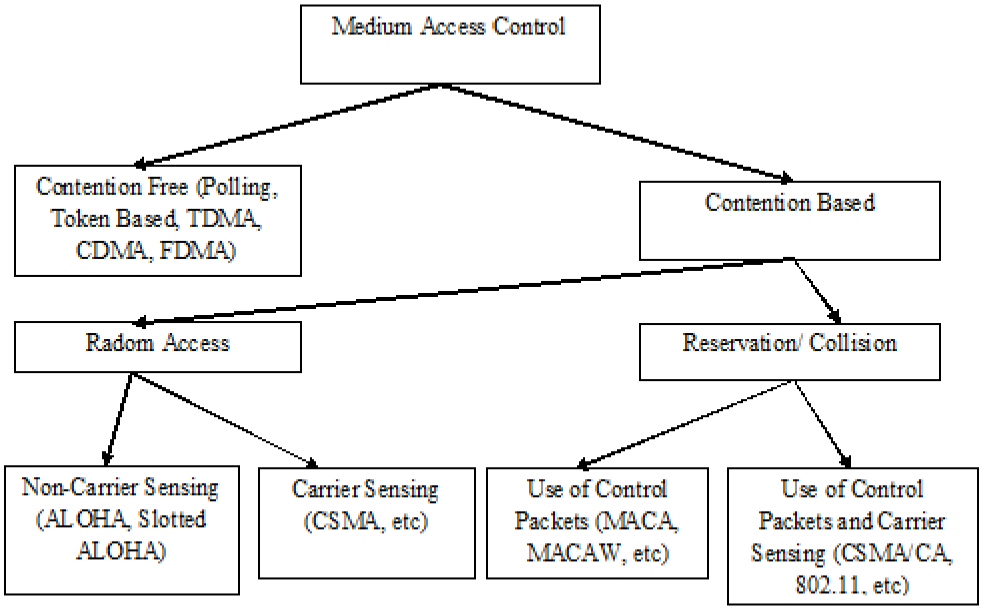

Figure1.2: Classification of MAC Protocols

The contention based MAC protocols can be divided into two groups known as Random Access and Reservation/ Collision Resolution MAC protocols. In Random access based schemes, such as ALOHA, a node may access the channel as soon as it is ready. Naturally, more than one node may transmit at the same time, causing collisions. ALOHA is more suitable under low system loads with large number of potential senders and it offers relatively low throughput. A variation of ALOHA, termed 'Slotted ALOHA', introduces synchronized transmission time slots similar to TDMA. In this case, nodes can transmit only at the beginning of the time slot. The introduction of time slot doubles the throughput as compared to the pure ALOHA scheme, with the cost of necessary time synchronizations. The CSMA based schemes further reduce the possibility of packet collisions and improve the throughput.

In order to solve the hidden and exposed terminal problems in CSMA, researchers have come up with many protocols, which are contention based but involve some forms of dynamic reservation/ collision resolution. Some schemes use the Request to Send (RTS)/

Clear to Send (CTS) control packets to prevent collisions, e.g. Multiple Access Collision avoidance (MACA) [12], MACA for wireless LANs (MACAW) [13] and also Wi-Fi 802.11 Std.

The contention based MAC schemes can also be classified as sender initiated or receiver initiated [3], single channel or multiple channel, power aware, directional antenna based and unidirectional link based schemes. The dynamic reservation approach involves the setting up of some sort of a reservation prior to data transmission. If a node that wants to send data takes the initiative of setting up this reservation, the protocol is considered to be a sender initiated protocol. Most schemes are sender initiated. In a receiver initiated protocol, the receiving node polls the potential transmitting nodes for data. If a sending node indeed has data for some receiver, it is allowed to transmit after being polled. The MACA – By invitation (MACA-BI) [14] and Receiver Initiated Busy Tone Multiple Access (RI-BTMA) [15] are examples of such schemes. MACA-BI is efficient in terms of transmit and receive turnaround times compared to MACA.

Another classification is based on the number of channels used for data transmission. Single channel protocols set up reservation for transmissions, and subsequently transmit their data using the same channel or frequency. Many MAC schemes like those mentioned earlier (MACA, MACAW and IEEE 802.11 Std.) use single channel. Multiple channel protocols use more than one channel in order to coordinate connection sessions among the transmitter and receiver nodes. The FCC mandates that all radios using ISM band must employ either DSSS or FHSS schemes. Several MAC protocols have been developed for using multiple channels through frequency hopping techniques, e.g. Hop-reservation multiple Access (HRMA) scheme [16]. Some others use special control signal on a separate channel for protecting the actual data that is transmitted on the data channel. For e.g. DBTMA (Dual Busy Tone Multiple Access) [17] has two narrow band signaling channels and one data channel. Two narrow bands send signals to protect the RTS and the DATA packets are sent on the data channel. This scheme achieves very high throughput and has negligible collisions. But disadvantage of this scheme is its high power consumption. It consumes almost double power as compared to IEEE 802.11 Std. protocol [18-21].

As we know, Adhoc Network has a major limitation of energy resource at each node. When a node dies it cannot forward packets to other nodes thereby hampering the connectivity of the network. Hence there has been a lot of research done in developing power aware protocols for the Adhoc networks. The power aware protocols are also divided depending upon which parameter the protocol is using to minimize the energy consumption e.g. optimizing the transmission power level. Such types of protocols which alter the transmission power level are known as Transmission Power Control Power Aware protocols. In the section given as follows, we explain all the transmission power control protocols with their advantages and disadvantages.

In the OPCM Optimistic Power Control MAC Protocol for Mobile Adhoc Networks [22], different power control mechanisms are used in the transmission and retransmission stages. The power level of the data packet is adjusted every time the DATA packet is retransmitted. In this protocol, the RTS and CTS packets are transmitted at maximum power level and the DATA and the ACK packets are sent at minimum required power level (or the desired power). This desired power level varies from minimum power level required to the maximum power level at which a node can transmit a packet. But this protocol has some disadvantages. In this MAC protocol the ACK packet is not completely protected by the RTS packet. The RTS is transmitted at maximum power levels and because the nodes reset the NAV which was initialized due to reception of RTS when they don't receive start of the DATA packet within a predefined time interval, the collision of

ACK packets may happen. Hence the throughput of OPCM is less than that of the IEEE 802.11 Std. Since OPCM protocol transmits RTS and CTS packet at maximum power level hence the throughput of the system doesn't increase as it is not making use of spatial reusability.

Another Wireless power aware MAC protocol is Power Control Medium Access Control (PCMAC) which tries to solve one of the disadvantages of OPCM MAC protocol. In this scheme [23], the RTS and CTS packets are sent with using the maximum power, whereas the DATA and ACK packets are sent with just the minimum power required for communication between the sender and receiver. They use closed loop power control in which the CTS and the DATA contain the feedback which tells the other node at what minimum power to transmit the packet in such a way that this node receives the packet. The source node periodically transmits the DATA packet at the maximum power level, for just enough time so that the nodes in the carrier sensing range, such as A may sense it. The scheme achieves considerable improvement in power consumption but since the error floor reserved with the use of RTS and CTS is same as that of the IEEE 802.11 Std, the throughput doesn't improve. Due to periodic transmission of DATA packets at maximum power, the throughput doesn't degrade. But the complexity of the transceiver device increases due to fast and periodic change of transmission power thereby increasing the cost. This protocol achieves higher throughput than the OPCM protocol.

In Minimum Power control in Adhoc Networks [24, 25], the transmission power is dynamically changed in such a way that it is the minimum required for a packet to reach the intended receiver. These protocols also use RTS, CTS, and DATA for communication but all the packets are sent at minimum power. There are two MAC protocols based on the mentioned principle. The Minimum Power Control achieves considerable amount of power saving as well as improvement in throughput as compared to IEEE 802.11 standard.

1.4 Routing Protocols

Due to the dynamic nature of MANETs, designing communications and networking protocols for these networks is a challenging process. One of the most important aspects of the communication process is design of the routing protocols which are used to establish and maintain multi-hop routes to allow the data communication between nodes. A considerable amount of research has been done in this area, and many multi-hop routing protocols have been developed. Most of these protocols such as the DSDV [6], Dynamic Source Routing protocol (DSR) [7], Adhoc on-Demand Distance Vector routing protocol (AODV) [8], Temporally Ordered Routing Protocol (TORA) [9], and others establish and maintain routes on the best-effort basis. While this might be sufficient for a certain class of MANET applications, it is not adequate for the support of more demanding applications such as multimedia audio and video. Such applications require the network to provide guarantees on the Quality of Service (QoS).

Some researchers have been active in the area of QoS support in MANETs, and have proposed numerous QoS routing protocols for this environment. Some of these protocols provide QoS support for the link availability for a given path. This is because link availability prediction improves the service of routing protocols. In this thesis, we have discussed link availability between nodes in the networks.

1.4.1 Routing Protocol Strategies

There are three basic Adhoc routing strategies. One is called Table-driven or proactive routing strategy, the second one is source-initiated and is called as demand-driven or reactive strategy. In addition to these two basic methods, third one is hybrid approach that utilizes some of the functionality from both the proactive and reactive strategies. Figure 1.3 depicts this classification.

1.4.1.1 Proactive strategy: In proactive scheme, every node continuously maintains the complete routing information of the network. When a node needs to forward a packet, the route will be readily available; thus there is no delay in searching for a route. However, for a highly dynamic topology, the proactive schemes will spend a significant amount of scarce wireless resource in maintaining the updated routing information correct. Examples of these protocols based on this strategy are Destination Sequenced Distance Vector (DSDV) Routing [6] and Optimized Link State Routing.

1.4.1.2 Reactive strategy: In reactive schemes, nodes only maintain routes to active destinations. A route search is needed for every new destination. Therefore, the communication overhead is reduced at the expense of route setup delay due to route search. These schemes are preferred for the adhoc environment since battery power is conserved both by not sending the advertisements as well as not to receiving them.

1.4.1.3 Hybrid strategy: In hybrid strategies, this protocol divide the network into zones (clusters) and run a proactive protocol within the zone and a reactive approach to perform routing between the different zones. This approach is better suited for large networks where clustering and partitioning of the network is very common.

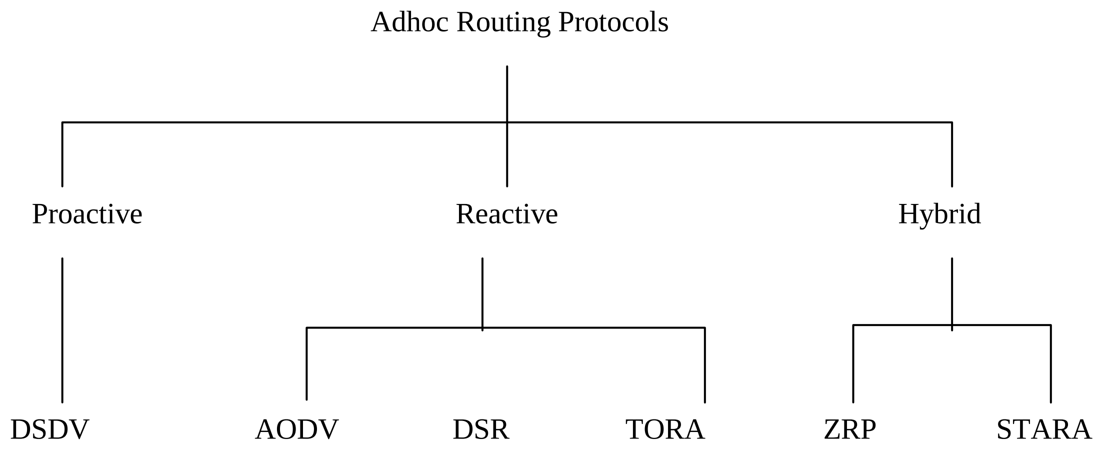

Figure 1.3 categorization of Adhoc routing Protocols

1.4.2 Destination-Sequenced Distance Vector (DSDV)

One of the first routing protocols for MANETs is Destination Sequenced Distance Vector (DSDV) [6], which can be called an adaptation of the Bellman Ford Distance Vector protocol for MANETs. Packets are transmitted between the nodes in the network by using the routing tables which are stored at each node of the network. Each node's routing table lists all available destinations, next hop node and the number of hops to reach there. Each routing table entry is tagged with a sequence number which is generated by the destination node. In AODV, the sequence number serves the purpose of avoiding loops in the route and to indicate their freshness. To maintain the consistency of routing tables in a dynamically varying topology, each node periodically transmits updates in addition to transmitting updates when significantly new information is available. Thus DSDV is a proactive protocol. Route advertisements are sent by broadcast or multicast. In order to reduce the amount of information carried by these advertisements, two types of packets are defined. One carries all the available routing information, and is called “full dump". The other type carries only information changed since the last full dump, and is called the “incremental". Full dumps are transmitted infrequently when no movement of mobile hosts is occurring. When node movements become frequent and the size of the incremental approaches the size of a network protocol data unit (NPDU), then a full dump can be scheduled. To further reduce the traffic, the advertisement of the routes which may not have stabilized yet is delayed. When a mobile host receives new routing information, that information is compared to the information already available from previous routing information packets. Any route with a more recent sequence number is used. Routes with older sequence numbers are discarded. A route with a sequence number equal to an existing route is chosen if it has a better metric such as smaller number of hops. When a link to the next hop of a route is broken, any route through that next hop is immediately assigned an infinite metric and an updated sequence number. The modifications are immediately broadcast in a routing information packet.

1.4.3 Adhoc On-demand Distance Vector (AODV) Routing

Adhoc On-demand Distance Vector (AODV) is the currently most popular routing protocol for MANETs. In this protocol, a node discovers a route on demand, i.e., only when it is needed, and caches it. Network wide flooding is used to discover the routes. This protocol requires that nodes maintain local connectivity information by sending periodic local (1-hop) broadcast messages known as hello messages. Through these hello messages a node becomes aware of its neighbors or nodes in its radio range. When a source node wants to send a message to a destination node and a route to the destination is not available in the cache, it initiates a path discovery process by broadcasting a route request (RREQ) packet. When a node receives a RREQ packet it checks whether it has received the same packet before, if it has then it discards the packet. The node then determines whether it has a route to the destination node in its cache. If it cannot satisfy the route request of the source then it rebroadcasts the packet after setting up a reverse path to the source. To set up a reverse path, a node records the address of the neighbor from which it received the first copy of RREQ as the next hop to the source. Eventually a RREQ arrives at a node (possibly the destination itself) that possesses a current route to the destination. Then node unicasts a route reply (RREP) packet back to the source. As the RREP travels back to the source, each node along the path sets up a forward pointer to the node from which the RREP was received as the next hop to the destination and updates its timeout information for the route entries to the source and destination. Nodes that are not part of the path determined by the RREP, timeout after ACTIVE_ROUTE_TIMEOUT and delete the reverse path to the source.

When a node detects that a destination node is unreachable (a link failure is detected either by failure to receive hello messages or a link-layer acknowledgement), it propagates to all the active neighbors a route error (RERR) packet for the failed routes for which the node was the next hop.

For each route entry a list of active neighbors is also maintained. A neighbor is considered active if it originates or relays at least one packet for that destination within the most recent ACTIVE_TIMEOUT period. All routes in the route table cache are tagged with destination sequence numbers which guarantees that no routing loops can form, even under extreme conditions of out-of-order packet delivery and high node mobility. The sequence number also helps in checking the freshness of a route, the greater the sequence number the more fresh a route is.

Several extensions have been proposed to the basic AODV routing protocol. Some of the most prominent ones have been accepted as part of standard AODV. One such modification is use of link layer feedback to maintain neighborhood information instead of periodic hello messages. Another modification is the use of expanding ring search for route request packets. Instead of sending a network wide broadcast for a RREQ, the source node starts out by sending a limited broadcast (done by setting the TTL (time to live) field in the packet to TTL_START). If this broadcast fails (indicated by a timeout) to find a route to the destination then the source increases the previous TTL value by TTL_INCREMENT and sends out another broadcast with the higher TTL value. This process is repeated till the TTL value reaches TTL_THRESHOLD after which the source sends out a broadcast with TTL equal to NETWORK_DIAMETER. If this broadcast also fails to discover a route to the destination then such broadcasts are sent again upto RREQ_RETRIES. If still a route cannot be found then all the packets queued for that destination are dropped. When RREQ_RETRIES is 0, the timeout for each RREQ is calculated as

Timeout = Min(2.0* TTL * LINK_TRAVERSAL_TIME, MAX_RREQ_TIMEOUT) .

Here LINK_TRAVERSAL_TIME is the time taken to traverse a link and MAX_RREQ_TIMEOUT is the maximum possible value of the timeout. When RREQ_RETRIES is greater than 0 then the timeout of each RREQ is calculated as

Timeout = Min(2.0 * TTL * LINK_TRAVERSAL_TIME * RREQ_RETRIES, MAX_RREQ_TIMEOUT) .

1.4.4 Dynamic Source Routing (DSR)

Dynamic Source Routing (DSR) is another reactive routing protocol and is similar to AODV in operation. The main difference between AODV and DSR is that DSR performs source routing, while AODV uses next-hop information stored in the nodes of the route. Source routing is a routing technique in which the sender of a packet determines the complete sequence of nodes through which to forward the packet; the sender explicitly lists this route in the packet's header, identifying each forwarding hop by the address of the next node to which to transmit the packet on its way to the destination node. The route discovery process in DSR is similar to AODV. When a node wants to send a packet to another host it checks its route cache for a route to the destination. If the route is not available in the cache then the node broadcasts a route request packet containing the identity of the destination. In addition to the address of the source and destination, each request packet contains a route record, which is accumulated record of the sequence of hops taken by the route request packet as it propagates through the adhoc network during route discovery. When a packet reaches at a node that does not contain the route to destination, it appends its address to the route record in the request packet and rebroadcasts the request further. When a packet reaches at a host (including can also be the destination) that has a route to the destination, the host appends the route to the accumulated route record in the packet and sends a route reply. In order to return the route reply packet to the initiator of the route request packet, the node must have a route to the initiator. If it has a route entry for the initiator in its route cache then the route reply packet is unicast to the initiator. Otherwise, the node can reverse the route in the route record of the route request packet, and use this route to send the route reply packet. This, however, requires the wireless links to work equally well in both directions, i.e., the wireless links must be bidirectional. If this condition is not true, then the host can piggyback the route reply packet on a route request packet targeted at the initiator of the original route discovery.

1.4.5 Temporally Ordered Routing Algorithm (TORA)

Temporally Ordered Routing Algorithm (TORA) is a distributed protocol designed to be highly adaptive so that it can operate in a dynamic network. For a given destination, TORA uses a somewhat arbitrary ‘height’ parameter to determine the direction of a link between any two nodes. As a consequence of this multiple routes are often present for a given destination, but none of them are necessarily the shortest route. For a node to initiate a route, it broadcasts a query to its neighbors. This is rebroadcasted through the network until it reaches the destination, or a node that has a route to the destination. This node replies with an update that contains its height with respect to the destination, which is propagated back to the sender. Each node receiving the update sets its own height to one greater than that of the neighbor that sent it. This forms a series of directed links from the sender to the destination in order of decreasing height. When a node discovers link failure, it sets its own height higher than that of its neighbors, and issues an update to that effect reversing the direction of the link between them. If it finds that it has no downstream neighbors, the destination is presumed lost, and it issues a clear packet to remove the invalid links from the rest of the network.

An advantage to TORA is that it supports multiple routes between any source-destination pair. Failure or removal of one node is quickly resolved without source intervention by switching to an alternate route. Unfortunately, there are drawbacks to TORA as well. The most glaring being that it relies on synchronized clocks among nodes in the network. If external time sources are present - (e.g. GPS), it makes the supporting hardware to support it more costly, and introduces a single point of failure if the time source became unavailable. TORA also relies on intermediate lower layers for certain functionality. It assumes, for example, that link status sensing, neighbor discovery, in-order packet delivery, and address resolution are all readily available. The solution is to run the Internet MANET Encapsulation Protocol (IMEP) at the layer immediately below TORA. This makes the overhead for this protocol difficult to separate from that imposed by the required lower layer.

1.5 Cross Layer Design in Wireless Adhoc Networks

The wide spectrum of applications demonstrates that MANETs have some distinct advantages over wired networks, mainly due to their fault-tolerant and self-organizing characteristics. At the same time, mobile adhoc network present a number of complexities and design constraints that are not existent in wired networks. The most important factor characterizing a MANET is the high variability of the network state. We use the term *network state* to refer to the wide range of communication conditions a node can experience in a MANET. The most important factors characterizing the network state are the link connectivity, the power control and the mobility effect [29].

1. *Link Connectivity*: In wired network, the link connectivity is a binary value i.e. a link exists between two nodes when they are connected by a physical medium like cable or optical fiber. In a MANET, the broadcast nature of the communication allows each node to be connected with multiple receiver nodes. Mobility of the nodes and small-scale channel variations due to fading, scattering and multipath can change the quality of a link within a few milliseconds. The variable link connectivity increases the number of packets dropped for transmission errors and has direct impact on all the network protocols. The MAC layer may assume that packet drop is caused by collisions and therefore it increases its backoff window. At transport layer, the TCP sender may misinterpret losses as congestion, and may react invoking congestion control and slow start recovery, thus reducing end-to-end performance of the current flow.
2. *Power control*: The broadcast nature of the wireless communication determines that each node may increase/reduce the number of neighboring nodes by tuning its

transmitter power. Thus, the topology of the network as perceived by each node is strongly dependant on the transmit power of each node. Increasing the transmit power also increases the effect of hidden and exposed nodes at the MAC layer and affects the congestion level of the wireless channel. This consumes more energy also, which is of no use.

3. *Mobility effect*: The nodes in a MANET are free to move and organize themselves arbitrarily. The mobility affects the performance of the network protocols. At the MAC layer mobility factor governs how long the measurements regarding channel state and interference remain valid. At routing layer, the mobility factor governs the performance of the routing protocols. At the transport layer, route failures can be misinterpreted as congestion effects and produce performance decay.

Meeting the requirements of the application despite variable link connectivity, network topology and power levels imply two issues in protocol design:

- *Information sharing:* Each layer of the protocol stack should be able to access the information about the current network state.;
- *Protocol cooperation:* Performance gains may be obtained if cross layer/ joint solutions at multiple network layers are considered.

The layered network architecture is well suited for wired networks but it is suboptimal in many applications of MANETs [29, 30, 31] due to variable link connectivity, mobility and power control. The main limitation of the layered model is the lack of cooperation among non-adjacent layers: each layer works in isolation with little information about the network. Moreover, the strict modularity does not allow to design cross-layer/ joint solutions optimized to maximize the overall network performance.

Cross layer design is used to support flexible layer approaches in MANETs [29, 30, 31]. Generally, cross layer design refers to protocol design done by allowing layers to exchange state information in order to obtain performance gains. Protocols use the state information flowing throughout the layered stack to adapt their behavior accordingly. The term state or network state is used to represent the wide range of communication conditions a node can experience in a MANET. For example, given current channel and energy conditions, the physical layer may adapt rate, power and coding to meet application requirements. The cross layer design introduces the advantages of explicit layer dependencies in the protocol stack, to cope with poor performance of wireless links, nodes' mobility, high error rates, power savings requirements, and Quality of Service.

1.6 Motivation for the Thesis

As we have seen in the earlier section in wireless adhoc networks, it is important to have optimization across the layers in adhoc networks in order to support Quality of Services in MANETs. Cross layer design raises the possibility of improving the performance of mobile adhoc networks. The cross layer optimization focuses on joint solutions involving more than one protocol layers. This motivates the cross layer design as the need for the protocols to be adaptive to network dynamics - mobility and to tackle the constraints i.e. - limited energy.

1.7 Problem definition

In the present work, we investigate and find out solution for cross layer optimization of protocols in mobile adhoc networks in providing service quality. The present work focuses to provide solutions that result in reduced link failures and increased battery life of the nodes by interactions of non-immediate layers. Further, it aims to use link prediction with routing protocol to avoid link breaks at network layer and use of controlled power to transmit control and data packets at MAC layer for power optimization.

1.8 Objectives

The following objectives have been set to achieve the proposed work in the problem definition:

1. Develop a model for link prediction. Incorporating link prediction model developed in the routing information. Use link prediction for advance route discovery. Evaluate the performance of the link prediction model.
2. Modification of the existing power optimization protocol in order to save energy and maximize the network throughput.
3. Propose a cross layer design for power control and link availability in order to improve the performance of mobile adhoc networks. Incorporating link prediction at network layer and power optimization protocol at MAC layer. Evaluate its performance.

1.9 Contributions of the thesis

The contribution of this thesis is cross layer optimization for protocols in mobile adhoc networks to support Quality of Services. This includes cross layer interactions between physical and network layers for link availability and power control at MAC layer.

Most of routing protocols provide best effort service and they are not concerned about quality of service. Mobile Adhoc Networks are characterized by dynamic topology due to nodes' mobility. Mobility is the main cause of the link failures that affects the services offered by the networks. So in this thesis, we are predicting the availability of the link using Newton divided difference interpolation method.

The battery life of the nodes is also another factor affecting the link availability. Due to limited battery power, once they die out the network connectivity changes. It is also important to optimize the MAC layer to reduce the consumption of power as adhoc nodes have limited battery power. We have proposed dynamic power control protocol for power optimization. Further, cross layer design for the dynamic power control protocol and link prediction (DPCPLP) is proposed that combines the effect of optimum transmit power and received signal strength based link availability using cross layer approach. This method uses optimum transmit power for transmitting the packets to a neighboring node to increase the battery life of adhoc nodes and received signal strength based link prediction to increase the availability of the links.

1.10 Organization of the Thesis

The thesis is organized as follows:

Chapter 1: Introduction: we have explained the basics of wireless adhoc networks, and discussed popular routing protocols used, and many power aware protocols. An overview of cross layer designs overview with their advantages and disadvantages in brief have also been given. In this chapter we have also presented the motivation to pursue the problems in this field.

Chapter 2: Wireless MAC, Routing Protocols and Cross Layer Design: we have explained the related MAC, routing protocols and cross layer designs in depth. We have also explained their advantages and disadvantages.

Chapter 3: Link Prediction Model: we have explained our first novel Link Prediction Model using Newton divided difference method for Mobile Adhoc Networks in detail. We have shown the results and the analysis for Link Prediction model with AODV routing algorithm.

Chapter 4: Dynamic Power Control Wireless MAC Protocol: we have explained our second novel wireless MAC protocol in detail. We have shown the results and the analysis for Dynamic Power Control wireless MAC protocol.

Chapter 5: Cross layer design for Link Availability and Power Control in Mobile Adhoc Networks: we have explained our third novel cross layer design for Link availability and Power Control in detail. We have shown the results and the analysis of cross layer design for link availability and power control.

Finally, chapter 6 concludes the thesis and also gives recommendations for future work.

CHAPTER 2

Wireless MAC, Quality of Service Routing and Cross Layer Protocols

In this chapter, we are going to describe wireless MAC, Quality of Service routing and cross layer protocols for mobile adhoc networks in detail.

2.1 Wireless MAC Protocols

In this section, two wireless MAC protocols are discussed. These are IEEE 802.11b Std. and Minimum Transmit Power Control wireless MAC protocols for Mobile Adhoc Networks.

2.1.1 IEEE 802.11b Std.

IEEE 802.11b Std. supports three modes of wifi MAC protocol – i) Distributed Coordination Function (DCF), ii) Point Coordination (PCF) and iii) Hybrid Coordination Function (HCF). Out of these three we are considering only Distribution Coordination Function. In DCF, there are two schemes of MAC protocols. One is Basic Access scheme and other is the scheme with Virtual carrier sensing using RTS-CTS handshake. The basic access Scheme doesn't make use of RTS-CTS packets. Hence there will be collisions of DATA packets. It take into account the hidden terminal problem. So the collisions of DATA packets in case of Basic Access Scheme are far more in the scheme with virtual carrier sensing using RTS-CTS handshake. Further, the RTS-CTS based scheme is described in detail.

Before we move on to the description of the RTS-CTS scheme we first have to understand the different types of Inter Frame Spacing (IFS) defined in the IEEE 802.11b Std. An IFS is the time interval between the packets or frames. The carrier sense mechanism at the Physical layer gives the information about the channel condition to the MAC layer at every time instant. A station or a node will be able to determine the idle channel and the instant when to transmit by studying the interval for which the channel is idle and comparing it with various IFS. Five different IFS are defined to provide priority levels for access to the wireless media. These are as follows:

- SIFS (Short Inter Frame Spacing)
- PIFS (PCF Inter Frame Spacing used only in point Coordination Function)
- DIFS (DCF Inter Frame Spacing)
- AIFS (Arbitration Inter Frame Spacing used by the QoS facility)
- EIFS (Extended Inter Frame Spacing)

Out of these five IFS, we will describe three types of IFS (SIFS, DIFS and EIFS) as PIFS is used only in Point Coordination Function and AIFS is used for the QoS implementations.

SIFS (Short Inter Frame Spacing)

The SIFS is the time which should elapse after end of the last symbol of the previous frame, before subsequent frame can be transmitted by any node. The nodes wait for SIFS prior to transmission of an ACK, CTS frame or the DATA packets. The SIFS frame is the shortest duration (spacing) between two consecutive frames. Duration of the SIFS is 10 microseconds.

DIFS (DCF Inter Frame Spacing)

The DIFS is used by stations/nodes operating under the DCF to transmit data frames. A station using the DCF shall be allowed to transmit if its carrier sensing (CS) mechanism determines that the medium is idle for DIFS period after a correctly received frame, and its back-off time has expired. DIFS is an interval between end of one successful communication and start of the contention for the next DATA transmission.

EIFS (Extended Inter Frame Spacing)

When a node receives an erroneous packet (collided packets or packet with bursty errors) it doesn't contend for the EIFS duration. EIFS duration is 200 microseconds. It is usually used by nodes when they fall in carrier sensing region and not in the transmission region. In the carrier sensing region they can just detect a packet and not decode it successfully. So the node treats the packet as noise and keeps quite for EIFS duration.

2.1.2 RTS-CTS-DATA-ACK four way handshake MAC protocol

The figure 2.1 gives a description about how the MAC protocol works. When a node has a packet to send, it first sends an RTS packet. The RTS packet contains the source MAC address, destination MAC address and NAV (Network Allocation Vector). NAV field contains the time interval for which the complete communication would continue. When the desired destination node receives this packet, it first confirms that the RTS is meant for it by comparing the destination MAC address. If this node is ready to receive packet from the sender, then it sends back the CTS packet. CTS packet contains the destination MAC address and NAV.

The receiver node calculates the remaining time from the NAV which it observes from RTS packet and inserts it in the CTS packet. After sending RTS packet the sender waits for SIFS period of time to receive CTS packet. If it starts receiving the CTS packet within that time then after it receives CTS it starts sending DATA packet after SIFS interval. Once the DATA is received correctly by the receiver, it starts sending the ACK packet after SIFS interval. ACK packet contains only the destination MAC address. Once the ACK packet is received by the sender, send by the receiver, it assumes the DATA transfer to be successful.

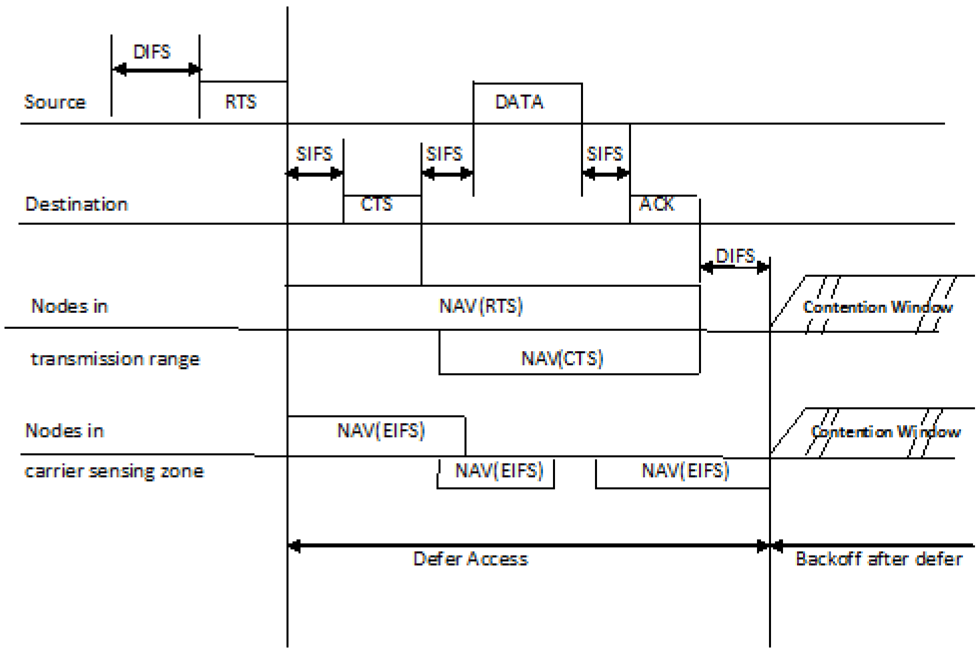

Figure 2.1: RTS-CTS-DATA-ACK four way handshake MAC Protocol

In this four way handshake MAC protocol a concept of virtual sensing is used. RTS packet contains the duration for which the communication is going to last. This duration contains SIFS + CTS + SIFS + DATA + SIFS + ACK time. Whenever a node receives RTS packet which is not meant for it, it sets its NAV to the NAV contained in the RTS packet. This means that even if the node senses the channel to be idle, still it won't transmit packet until and unless the NAV is not zero. This node also sets another time out. This time out is equal to SIFS + CTS + SIFS + Turnaround time. If it doesn't receive the start of the data within the time interval then it assumes that the RTS-CTS handshake wasn't successful and hence it resets the NAV which it had set earlier. When a node receives a CTS packet which is not meant for it, it checks the NAV value contained in the CTS packet. It sets its NAV value to the NAV in the CTS packet. Hence the node will defer to access the channel for the NAV period according to the virtual carrier sense mechanism. Once the NAV of each nodes becomes zero as it is decremented with time, every node will defer to access the channel for DIFS period. If the nodes do not receive anything within that period then they will start contending for the channel, otherwise they will wait for the channel to become idle again.

Backoff Mechanism

If a node wants to transfer DATA packet then it checks whether the channel is idle or busy through carrier sensing. If the medium is busy, the STA shall defer until the medium is determined to be idle without interruption for a period of time equal to DIFS when the last frame detected on the medium was received correctly, or after the medium is determined to be idle without the interruption for a time equal to EIFS when the last frame detected on the medium was not received correctly. After this DIFS and EIFS medium idle time, the STA shall then generate a random backoff period for an additional deferral time before transmitting, unless the backoff timer already contains a nonzero value, in which case the selection of a random number is not needed and not performed.

$$\text{Backoff Time} = \text{Random}() \times \text{Slot Time} \qquad (2.1)$$

Random () is a Pseudo random integer drawn from a uniform distribution over the interval [0, CW], where CW is the contention window $CW_{min} \leq CW \leq CW_{max}$. CW_{min} is 32 and CW_{max} is 1024 for DSSS. Slot time depends upon physical layer but is 20 microseconds for DSSS. CW is first initialized to CW_{min}. After every unsuccessful transmission, the CW is double until it becomes CW_{max} after which it is not increases. After 10 transmissions the packet is discarded as corresponding message is send to the higher layer. If some other node starts transmitting packets before the node's backoff counter becomes zero then the node freezes the backoff counter and decrements only after it starts sensing the channel.

2.1.3 Minimum transmit Power Control MAC Protocol

Unlike in IEEE 802.11b Std MAC protocol, in these schemes the transmission power is not kept constant. Every node transmits at different power to different neighbors. The packets are transmitted in such a way that transmission power is less and still the receiver is able to receive the packet correctly. So in these protocols, the authors have tried to reduce the power consumption of the node by making the node transmit the packets at least power. The authors have made changes in field of CTS and DATA packets to include some more information about the power control. The basic concept of these protocols is that every node tries to transmit packet at minimum power level required to reach the destination node. The two minimum power control protocols are Adaptive Power Control MAC Protocol for Adhoc Networks [24] and Distributed Power Control in Adhoc networks [25]. These protocols are similar to each other, difference being that adaptive power control uses Open loop power control whereas distributed power control uses closed loop power control to find out the minimum power level required so that the destination node is able to decode the packet successfully. We will describe Adaptive power control protocol after distributed power control protocol.

Distributed Power Control, the transmitted power level is allowed to be any one of the maximum and one length of this value. The message header formats of the CTS, DATA and ACK are altered to include a value which is the ratio of the received signal strength at the node currently transmitting the message. When a receiver receives a RTS message, it will encode the ratio of the received signal strength of the RTS message to the minimum signal strength that is acceptable by the receiver in the header of the CTS reply message. Similarly, when transmitting the DATA message, the transmitter will encode into it the ratio with respect to the received CTS. Thus, during one RTS-CTS-DATA-ACK exchange, both the transmitter and the receiver inform each other about the quality of their transmitted signals. Both nodes now have the opportunity to alter their transmit power levels for further communication between each other.

The MAC layer for each node maintains a small table that stores power control settings for other nodes with which this node has recently communicated. The table will be small since it is unlikely that a node will communicate directly with more than few neighbours at any point of time. The table stores the current transmit power level settings used for each neighbour. The cf-pwr field of the table maintains a EWA (exponential weighted average) history of the received signal strength ratio received from each neighbour. The dr-pwr field maintains a EWA history of the cf-pwr at instances when packet losses occurred. A count down timer field is also maintained for each neighbour to dampen fluctuations in transmit power levels.

If a node wants to send a packet to another node, then it first checks the node ID in its table and sends at the respective power level mentioned in the table. If there is no entry in the table then it sends the packet at maximum power level and also makes corresponding entry in the table. When a CTS or DATA message is received from a node, we update its cf-pwr field in the table. If the cf-pwr is higher than the dr-pwr field, we decrement the transmit power level field by one, unless the count down timer field is not null. When the MAC times out while waiting for a CTS or DATA or ACK message from a node, we increment the transmit power level field by one and update the dr pwr field. We set the count down field to ten. This ensures that for the next ten message transmissions to this node, the transmit power level field will not be decremented. We close the value of ten to dampen rapid fluctuations while ensuring the overall effectiveness of the power control loop. The essential goal of this protocol is to learn the minimum transmit power level required for a node to successfully transmit to a neighbouring node. Starting with an initial value for the transmit power level, the exchange and loss of messages causes the MAC layer to step up (or down) the transmit power level. The MAC layer of a route thus learns the unique minimum transmit power level required for that node to successfully transmit to any other nearby node.

In **Adaptive Power Control** an open loop power control is used i.e. depending upon the received signal strength we estimate the minimum transmit power. The author has tried to limit te transmit power to a level just adequate to sustain a good communication quality. If the distance between the source and the destination is $d_{ij,}$ and the minimum detectable power is P_{min}, then the desired nominal transmission power level is given by

$$P_t = \frac{P_{min}}{G_t G_r} \left(\frac{4\pi d_{ij}}{\lambda}\right)^2. \tag{2.2}$$

However, if we don't have information about the distance between the two nodes then we can find out the transmission power by the equation:

$$P_t = \frac{P_{min} * P_t^{'}}{P_r^{'}}. \quad (2.3)$$

Where $P_t^{'}$ and $P_t^{'}$ are the transmission and received powers of the previous packet from that receiver to the sender, respectively and we assume that the propagation constants are known to the nodes. The propagation model considered above is a Two Ray Propagation Model. The $P_t^{'}$ is present in the header field of the packet received.

The authors have come up with two protocols based on the above principle. One is 2 level RTS power controlled (2RPC) protocol and the other is continuous RTS power controlled (CRPC) protocol. In 2RPC protocol, two power levels for the RTS packet are defined. When the destination is within the near zone from the source the low power level is used otherwise high power level is used. An extra field in the header of RTS, CTS and DATA is incorporated which indicates the transmission power level of next packet. A node first sends RTS packet at lower power level. If the destination node doesn't respond with CTS packet within a certain time period then the next RTS is sent at high power level. When the destination node receives the RTS packet it extracts the transmission power (Pt_{rts}), measures the received power of the RTS packet and computes the CTS packet transmission power,

$$Pt_{cts} = \frac{P_{min} * Pt_{rts} * P_{const}}{Pr_{rts}}. \quad (2.4)$$

Pt_{const} is a constant larger than 1 to overcompensate for the interference and noise. It inserts the transmit power into the CTS header. When the sender receives the CTS packet from the transmitter it executes the same steps the receiver did when it received RTS packet and thus finds out transmission power level for the DATA header. Similarly the receiver calculates the transmission power for ACK packet and transmits it.

$$Pt_{data} = \frac{P_{min} * Pt_{cts} * P_{const}}{Pr_{cts}}. \quad (2.5)$$

$$Pt_{ack} = \frac{P_{min} * Pt_{data} * P_{const}}{Pr_{data}}. \quad (2.6)$$

In CRPC protocol, the transmission power for the RTS is varied according to the distance of the source from the destination. This information is obtained from the two recent ACK packets received from the respective destination. In this protocol, we also incorporate the transmission power of ACK in the ACK packet. The formula for finding transmission power for the RTS is given below where two most recent ACK packets received and transmit powers are used.

$$Pt_{rts} = \frac{P_{min} * P_{const} * \sqrt{Pt'_{ack} * Pt_{ack}}}{\sqrt{Pr'_{ack} * Pr_{ack}}}. \quad (2.7)$$

The calculation of the transmission power for the other packets is similar to the 2-RPC protocol.

2.2 Quality of Service Routing

QoS is usually defined as a set of service requirements that needs to be met by the network while transporting a packet stream from a source to its destination. The network needs are governed by the service requirements of end user applications. The network is expected to guarantee a set of measurable pre specified service attributes to the users in terms of end-to-end performance, such as delay, bandwidth, probability of packet loss, delay variance (jitter), etc. Power consumption is another QoS [32] attribute which is more specific to MANETs. In the literature, the research on QoS support in MANETs spans over all the layers in the network:

- QoS models specify an architecture in which some kinds of services could be provided. It is the system goal that has to be implemented.

- QoS Adaptation hides all environment-related features from awareness of the multimedia-application above and provides an interface for applications to interact with QoS control.

- Above the network layer QoS signaling acts as a control center in QoS support. The functionality of QoS signaling is determined by the QoS model.

- QoS routing is part of the network layer and searches for a path with enough resources but does not reserve resources.

- QoS MAC protocols are essential components in QoS for MANETs. QoS supporting components at upper layers, such as QoS signaling or QoS routing assume the existence of a MAC protocol, which solves the problems of medium contention, supports reliable communication, and provides resource reservation.

QoS routing is difficult in Mobile Adhoc Network. First, Overheads of QoS is too high for limited bandwidth because mobile hosts should have the mechanisms to store and update link state information. Second, because of the dynamic nature of MANETs, maintaining the precise link state information is very difficult. Third, the traditional meaning that the required QoS should be ensured once a feasible path is established is no longer true. The reserved resource may not be guaranteed because of the mobility- caused path breakage or power depletion of the mobile host.

QoS routing protocols search routes with sufficient QoS requirements. QoS routing protocol meet end-to-end QoS requirements, such as delay, bandwidth demand or multi metric constraints. The QoS metrics could be concave or addictive [32].

Definition of Concave and additive QoS metrics: Let m(i, j) be a QoS metric for link (i, j). For a path P = (s, i, j,…l, t), metric m is concave if m(P) = min{m(s,i), m(i,j),…m(l, t)}. Metric m is additive if m(P) = m(s, i)+ m(i, j) +…+m(l, t). The bandwidth metric is concave and delay metric is additive.

2.2.1 Quality of Service in Adhoc Networks

This section discusses unique issues and difficulties for supporting QoS in a MANET environment and ends up showing the major drawbacks of each of the two QoS architectures described above with respect to these characteristics.

2.2.1.1 Special Issues and Difficulties in MANETS

MANETs differ from the traditional wired Internet infrastructures. The differences introduce difficulties for achieving Quality of Service in such networks. The following list itemizes some of the problems:

- **Dynamic topologies:** Nodes are free to move arbitrarily; thus, the network topology which is t ypically multihop - may change randomly and rapidly at unpredictable times, and may consist of both bidirectional and unidirectional links.
- **Bandwidth-constrained, variable capacity links**: Wireless links will continue to have significantly lower capacity than their hardwired counterparts. In addition, the realized Throughput of wireless communications after accounting for the

effects of multiple access, fading, noise, and interference conditions, etc.- is often much less than a radio's maximum transmission rate.

One effect of the relatively low to moderate link capacities is that congestion is typically the norm rather than the exception, i.e. aggregate application demand will likely approach or exceed network capacity frequently. As the mobile network is often simply an extension of the fixed network infrastructure, mobile adhoc users will demand similar services. These demands will continue to increase as multimedia computing and collaborative networking applications rise.

- **Energy-constrained operation:** Some or all of the nodes in a MANET may rely on batteries or other exhaustible means for their energy. For these nodes, the most important system design criteria for optimization may be energy conservation.

Above defined characteristics of Mobile Adhoc Networks that may pose difficulties to provide QoS, like highly dynamic topology, lack of central controller, limited resource availability, hidden terminal problem, routing misbehavior and insecure medium. Some of the design [33] choices for providing QoS support are given as follows.

2.2.1.2 Hard state versus soft state resource reservation: QoS resource reservation mechanism can be broadly classified in to two categories: hard state and soft state reservation mechanism. In Hard state resource reservation schemes, resource are reserved at all intermediate nodes along the path from the source to the destination throughout the duration of the Quality of Service session. Soft state resource reservation mechanism maintains reservation only for small time intervals.

2.2.1.3 Stateful versus Stateless approach: In the stateful approach, each node maintains either global state information or only local state information, while in the case of a stateless approach, no such information is maintained at the nodes. State information includes both the topology information and the flow specific information. In the case of the stateless approach, neither flow-specific nor link-specific state information is maintained at the nodes.

2.2.1.4 Hard QoS versus Soft QoS approach: If the QoS requirements of a connection are guaranteed to be met for the whole duration of the session, the QoS approach termed a hard QoS approach. If the QoS requirements are not guaranteed for the entire session, the QoS approach termed a soft QoS approach.

The Quality of Service (QoS) routing in an adhoc network is difficult because the network topology may change constantly, and the available state information for routing is inherently imprecise. All the previous routing solutions only deal with the best-effort data traffic. Connections with quality-of-service (QoS) requirements, Delay, Bandwidth, Overhead Ratio and Power constraints, are not supported.

2.2.2 Classification of QoS Approaches

As shown in figure 2.2, many criteria used for classifying QoS approaches like based on interaction between routing protocol and QoS providing mechanism, interaction between network and MAC layers; and the routing information update mechanism employed. Based on interaction between routing protocol and QoS providing mechanism, QoS approaches can be classified in to two categories: coupled and decoupled QoS approaches. In coupled QoS approaches routing protocol and QoS provisioning mechanism closely interact with each other for QoS. Decoupled approaches QoS provisioning mechanism does not depend upon any routing protocol.

Interaction between network and MAC layers based approach is further classified in two categories: independent and dependent. Independent QoS approach, network layer does not dependent upon MAC layer for QoS provisioning. But in dependent approach network layer dependent upon MAC layer to provide QoS provisioning.

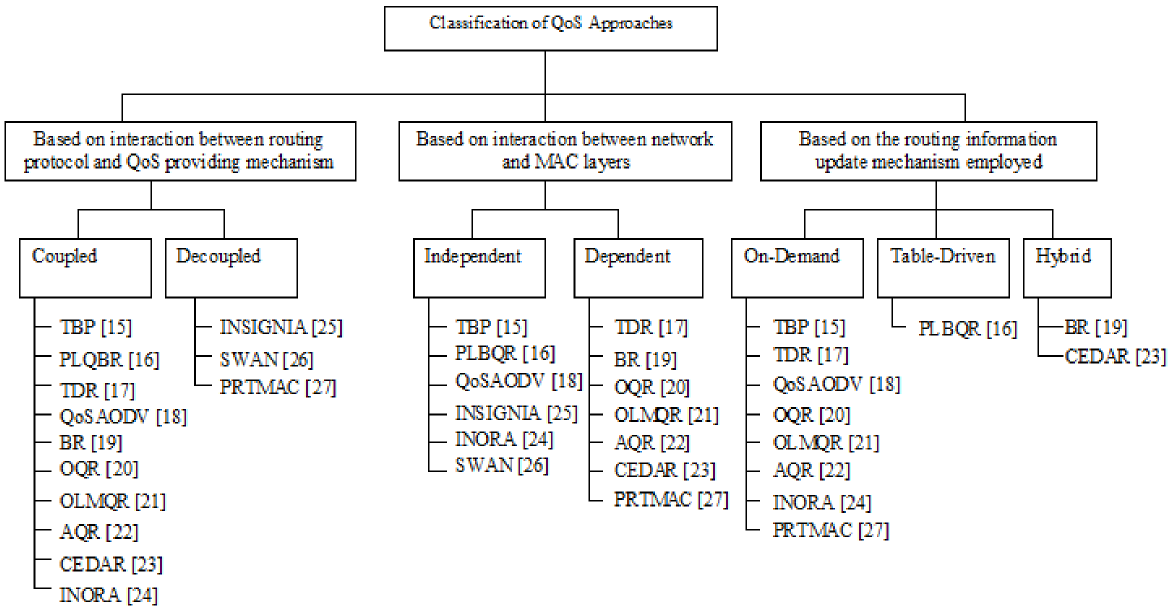

Figure 2.2 Classification of QoS approaches [33]

2.2.3 QoS Models

Today's Internet applies best effort (BE) IP forwarding [32]. The network attempts to deliver all traffic as soon as possible within the limits of its abilities, but without guarantees related to throughput, delay or packet loss. It is left up to the end systems to cope with network transport impairments.

Although best efforts remain adequate for most applications, QoS support is required to satisfy the growing need for multimedia over IP, like video streaming or IP telephony.

The existing QoS models can be classified into two types according to their fundamental operations; the Integrated Services (IntServ) framework provides explicit reservations end-to-end and the Differentiated Services (DiffServ) architecture offers hop-by-hop differentiated treatment of packets.

2.2.3.1 IntServ

The IntServ [47][48][49] model merges the advantages of two different paradigms: datagram networks and circuit switched networks. It can provide a circuit-switched service in packet-switched networks. The Resource Reservation Protocol (RSVP) was designed as the primary signaling protocol to setup and maintain the virtual connection. RSVP is also used to propagate the attributes of the data flow and to request resources along the path. Routers finally apply corresponding resource management schemes to support QoS specifications of the connection. Based on these mechanisms, IntServ provides quantitative QoS for every flow.

IntServ has the following salient shortcomings in MANET environments:

- **Scalability**: IntServ provides per-flow granularity, so the amount of state information increases proportionally with the number of flows. This results in a storage and processing overhead on routers, which is the well-known scalability problem of IntServ. The scalability problem is less likely to occur in current MANETs considering the small number of flows, the limited size of the network and the bandwidth of the wireless links. On the other hand, as the quality of wireless technology increases rapidly, high speed and large size MANETs may be a matter of fact some day. Though one could argue that whenever large high-performance MANETs will be developed in future, processing and storing capabilities will increase as well.

- **Signaling:** Signaling protocols generally contain three phases: connection establishment, connection maintenance and connection teardown. In highly dynamic networks such as MANETs this is no promising approach since routes may change very fast and the adaptation process of protocols using a complex handshaking mechanism would just be too slow. Furthermore the signaling overhead while maintaining the connection is a potential problem as well.

2.2.3.2 DiffServ

DiffServ [49][50] was designed to overcome the difficulty of implementing and deploying IntServ and RSVP in the Internet backbone and differs in the kind of service it provides. While IntServ provides per-flow guarantees, Differentiated Services (DiffServ) follows the philosophy of mapping multiple flows into a few service levels. At the boundary of the network, traffic entering a network is classified, conditioned and assigned to different behavior aggregates by marking a special DS (Differentiated Services) field in the IP packet header. Within the core of the network, packets are forwarded according to the per-hop behavior (PHB) associated with the DSCP (Differentiated Service Code Point). This eliminates the need to keep any flow state information elsewhere in the network.

The main drawbacks of a DiffServ approach in MANETs are listed as follows:

- **Soft QoS guarantees:** DiffServ uses a relative-priority scheme to map the quality of service requirements to a service level. This aggregation results in a more scalable but also in more approximate service to user flow.

- **Service Level Agreement (SLA):** DiffServ is based on the concept of SLA's. In the Internet an SLA is a kind of contract between a customer and its Internet Service Provider (ISP) that specifies the forwarding service the customer should receive. The Administration of a DiffServ domain must assure that sufficient resources are provisioned to support the SLA's committed by the domain. Moreover, the DiffServ boundary nodes are required to monitor the arriving traffic for each service class and to perform traffic classification and conditioning to enforce the negotiated SLA's. Generally speaking if someone acquires QoS parameters and he pays for such parameters then of course there must be some entity which will assures them. In a completely adhoc topology where there is no concept of service provider and client and where there are only clients it would be quite difficult to innovate QoS, since there is no obligation from somebody to somebody else what makes QoS almost infeasible.

- **Ambiguous core network:** The benefit of DiffServ is that traffic classification and conditioning only has to be done at the boundary nodes. This makes quality of service provisioning much easier in the core of the network. In MANETs though there is no clear definition of what is the core network because every node is a potential sender, receiver and router. This drawback would again take us back to the IntServ model where several separate flow states are maintained.

2.2.3.3 IntServ over DiffServ

This model provides a reservation-based QoS architecture with feedback signaling. It uses RSVP to signal resource needs but uses DiffServ as the technology to do the actual resource sharing among flows.

2.2.3.4 FQMM

Flexible Quality of Service Model for Mobile Adhoc Networks (FQMM) [32] combines the IntServ and the DiffServ model. In this model, three kinds of nodes are defined. An ingress node is a mobile node that sends data. Interior nodes are the nodes forwarding data for other nodes. An egress node is a destination node. The basic idea of FQQM is that it uses both the per-flow state property of IntServ and the service differentiation of DiffServ. This is achieved by preserving per-flow granularity for a small portion of traffic in the MANET, given that a large amount of the traffic belongs to per aggregate of flows, that is, per-class granularity. A traffic conditioner is placed at the ingress nodes where the traffic originates. It is responsible for re-marking or discarding packets according to the traffic profile, which describes the temporal properties of the traffic stream such as transmission rate and burst size.

FQMM is an interesting attempt at proposing a QoS model for MANETs, however it suffers of major problems:

FQQM aims to tackle the scalability problem of IntServ. But without an explicit control on the number of services with per-flow granularity, the problem still exists.

- Due to its DiffServ behaviors in ingress nodes, FQMM may not be able to satisfy hard QoS requirements It could be difficult to code the PHB in the DS field if the PHB includes per-flow granularity, considering the DS field is at most 8 bits without extension.
- How to make a dynamically negotiated traffic profile is a well-known DiffServ problem and FQMM seems not to solve it.

2.2.4 Related work

T. Goff and N. Abu-Ghazaleh *et al.* [51] have proposed a pre-emptive route maintenance extension to on-demand routing protocol. The received transmission power is used to estimate when the link is expected to break.

Shengming Jiang, Dajiang He and Jianqiang Rao [52] have proposed a prediction based link availability estimation model, for MANET. This model predicts the probability of an active link between two nodes being continuously available for a predicted period based on the movement of current nodes. They used exponential distribution for prediction of link availability. In this model authors considered the change of node movement, but did not consider the rate of change that may affect the prediction.

Liang Qin and Thomas Kunz [53] presented a method to increase packet delivery ratio in DSR. They have used the model for link prediction based on received signal strength, which is the function of distance between two nodes. A link between two nodes is available as long as the distance between the two nodes is smaller than the transmission range or the received signal strength is above a threshold.

Min Quin, Roger Zimmermann and Leslie S. Liu [54] develop a model predicting the availability of link between mobile peers for support multimedia streaming. The authors have presented a mathematical framework for analyzing the link predictability for a short duration.

Sofiane Boukli Hacene, Ahmed Lehireche and Ahmed Meddahi [55] have proposed predictive preemptive AODV (PPAODV), which predicts the link failure using the received signal strength (RSS). This prediction method uses Lagrange interpolation, which approximates the RSS by means of a function with past RSS information. PPAODV discovers a new route before the active route breaks and changes the route smoothly by predicting a RSS of data packets at the predict time t, from the past information of RSS. PPAODV also includes discovery period T_{DP} in the predicted time.

S. Crisostomo, S. Sargento, P. Brandao and R. Prior [56] have presented a proposal for link expiration time computation using GPS (Global Positioning system) equipped receiver. Though, no results and analysis were presented. It uses location and mobility information of the neighbors including longitude, latitude etc propagated through Hello messages.

P. Mani and D. W. Petr [57] have used a method for the calculation of velocity and thus link break time computation based on distance and velocity. The simulation results and analysis show that there is improvement in the end-to-end delay. For CBR traffic, there is reduction in packet delivery ratio using this model as compared to AODV. For TCP traffic, this does not give significant benefit in throughput over AODV.

Prashant Singh and D. K. Lobiyal [58] have proposed a prediction based link availability estimation model for MANET. This model predicts the probability of breakup an active link between two nodes based on the node movement. It uses pareto distribution for prediction of link availability to represent the pdf of epoch length. Epoch length is defined as the length of interval for which a node moves in a constant direction at a constant speed.They have used Pareto distribution with the assumption that small epoch length will occur more frequently and larger epoch length will occur less frequent.

Damla Turgut, Sajal K. Das and Mainak Chatterjee [59], present an algorithm that predict the expected lifetime of a link which is independent of speed and direction of nodes in the networks for different mobility model. Prediction of route life time they used transmission range of node. Some mobility models which are used by author in the literature are Deterministic, Partially deterministic and Brownian motion. In Deterministic model, movements of all nodes are completely defined so it is easy to calculate the time when they will move away from each other transmission range. Partially deterministic mobility model have movement of all nodes with certain probability. But in Brownian motion, motion of all nodes is random between 0 to 2π and velocity is random at any given time.

Dario Pompili and Marco Vittucci [60], proposed a probabilistic predictive multicast algorithm for adhoc networks. This algorithm predicts the next position of node so that it gets the stable links in the network. For the link prediction, authors used the power of nodes for link prediction and have given an analytical model for link prediction.

K´aroly Farkas, Theus Hossmann, Lukas Ruf, Bernhard Plattner [61], proposed an approach to predict link quality variation based on pattern matching which is affected by mobility of nodes. This approach called XCoPred. Author used SNR (Signal to Noise Ratio) for link prediction. When network needs prediction of link, nodes tries to detect the pattern similar to the current situation in the history of the SNR values of its link by applying the normalized cross-correlation function.

Michael Gerharz, Christian de Waal, Matthias Frank, Peter Martini [62], introduce adaptive metrics to find out the stable links in mobile adhoc network by prediction of link availability in several different mobility scenarios.

Adrin, Phillip, Cormac [63], proposed Link Cache Extension for Predictive Routing. They adopt the mobility model, which assumes a free space propagation model where the received signal strength is a function only of the distance to the transmitter (assuming a fixed radiated power from each node). Thus a link from node i to node j can be maintained as long as the distance between the nodes is less than the transmission range, r or equivalently the signal strength is above some threshold. Next, they assume that all nodes are capable of determining a position either through GPS or some other positioning system and that these positions are time stamped so that a velocity and bearing can be computed.

2.3 Cross Layer Design

In this section, two approaches ─ layered and cross layered, motivations for adaptation of cross layer design and existing cross layer designs are covered.

2.3.1 Layered vs Cross Layer approach

Traditionally, network architectures assume that communication functions are organized into protocol layers and packet deliveries are done with the help of protocol headers, one for each protocol layer. The network functionalities and services are carried through the layered network model. In a protocol stack each layer defines the specifications for a particular network aspect and provides services to the upper layer. The layers are modular and each layer implements a specific service. The architecture forbids direct communication between non-adjacent layers, while the communication between adjacent layers works by using standard interfaces.

Alternatively, protocols can be designed by violating the reference architecture, by allowing interactions and state information flowing among non-adjacent levels of the protocol stack. Generally, the cross layer design refers to protocol design done by allowing layers to exchange state information in order to obtain performance gains [29, 30, 31, 64, 65]. The difference between the layered and the cross-layer architecture is shown in figure 2.3.

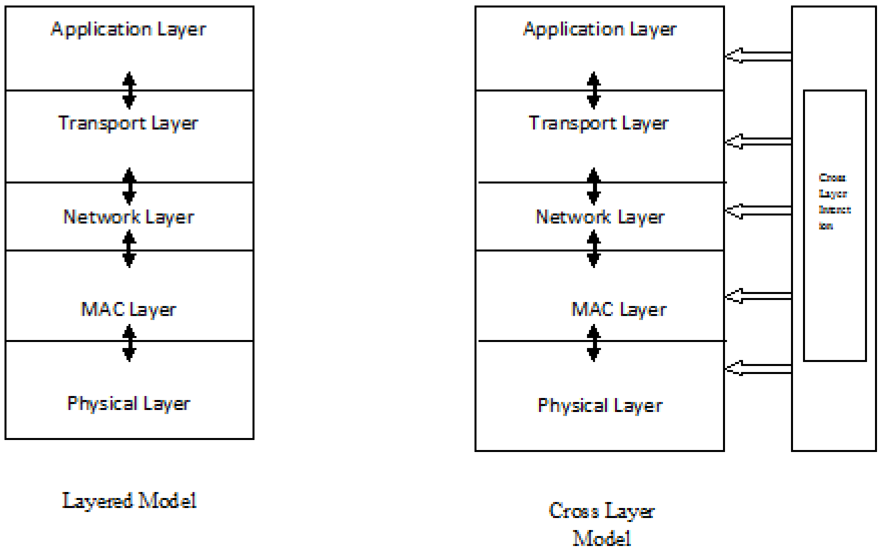

Figure 2.3: The layered and the cross layer architecture

2.3.2 Motivations for cross layer design

In this section, the general motivations supporting adoption of cross layer design in MANETs is followed. There are three main motivations supporting the adoption of cross-layer design in protocol design for MANETs; the need by protocols to be adaptive to network dynamics, to support the requirements specified by the applications and to tackle the energy and security constraints. It is observed that several design challenges in

MANETs - security, energy issue, topology control cut across the layers, and requires cross-layer solutions involving multiple protocol layers.

- **Adaptivity and Self- Organization**

Network protocols for MANETs must be adaptive to many factors to effectively support fair sharing of devices and resources and hide the system dynamics to the upper layers. The system dynamics includes a wide range of communication conditions a wireless node can experience inside a MANET, including changing topology, shared medium contention, varying traffic patterns and distributions. The adaptive behaviour can be implemented if the following requirements are met:

1. Context awareness, i.e. the knowledge of the parameters affecting the network state (channel condition, congestion, traffic demands, etc);
2. Protocol tuning, i.e. the possibility for each protocol to adjust its behaviour is according to the current state.

For example, given the current channel state condition (BER level), the MAC protocol may adjust some parameters (e.g. the length of the frame) in order to reduce energy consumption [66]. The routing layer may use the channel state information in the route discovery process, in order to dynamically select the most stable routes [67].

Context awareness sometimes requires to re-design the way protocols are organized and interact with each other. Cross layer architectures have been proposed to guarantee protocols cooperation with sharing of network-status information while maintaining separation among the layers [31].

- **QoS and Application Requirements**

QoS is a guarantee by the network to provide certain performance for a flow in terms of bandwidth, delay, jitter, packet loss probability, etc. At the Mac layer, QoS is related to the fraction of time a node is able to successfully access and transmit a packet. Actually, the 802.11e protocol extension provides mechanism to support different priorities in WLAN networks: the 802.11e EDCF [68] protocol supports 8 different service priorities mapped on 4 different access categories. Each category defines a set of parameters governing the access to the shared medium. In multi-hop environments, QoS must be addressed by considering the QoS requirements on the end-to-end path as well as on each hop. Wireless channel fluctuations, self-contention, limited bandwidth and dynamic topology make the QoS support very difficult. Therefore, many recent works investigate the cross layer optimization of physical layer power allocation, MAC layer link scheduling and network layer flow assignment [64, 67].

- **Energy Conservation**

Energy efficiency is a limiting factor in the successful deployment of MANETs, because nodes are expected to rely on portable, limited power sources. Moreover, energy conservation is extremely challenging in multi-hop environments, where nodes should also consume energy to route packets for other nodes and to guarantee the connectivity of the network. At the MAC layer, some techniques can be used to reduce the energy consumed during transmission and reception: additionally, a careful policy may turn off the wireless device when the node is idle. At the network layer, the route selection process should be performed by reducing the end-to-end power needed to forward the packet [70]: if the network layer may have access to energy information, battery level metrics can be used in the routing process.

- **Security**

Nodes in MANETs communicate with each other via open and shared broadcast channel, they are more vulnerable to security attacks. Moreover, the support for multi-hop communication implies that the network has to rely on individual solutions from each mobile node, resulting vulnerable to infiltration, eavesdropping, interference, DoS attacks. Many research efforts have concentrated on secure data forwarding, secure routing protocols face the attacks that disrupt topological information [71]. On the other hand, data-link security solutions are implemented as parts of wireless standards (WEP/WPA for 802.11) to provide authentication and privacy issue on infrastructural single-hop wireless networks [72]. However, the solutions proposed at MAC, routing and transport layer only cover a subset of all possible threats [71]. A cross layer design of MAC, routing and transport protocol allows to take into account the security issues in all the stages of protocol design.

2.3.3 Cross Layer Protocols

Due to dynamic, limited resources and unpredictable channel conditions, the traditional way of optimization at different layers is not enough in wireless adhoc networks. In order to obtain best results, it is necessary to perform optimizations using the information available across multiple layers. The concept of cross layer design, the layers exchange the information in order to improve the overall network performance. Many cross layer solutions across multiple layers have been considered in literature. In this section, cross layer solutions involving Physical (PHY), Medium Access Control (MAC), Network (NET) and Transport (TRA) layers. In most of them, cross layer feedbacks are used to enable state information flow from upper to lower layers or vice versa, while the traditional layered structure is preserved.

Physical and Network cross layer interactions: The impact of physical layer on five different routing protocols has been studied in [73]. The performance obtained when physical layer properties such as path loss and shadowing are considered are much better than the scenario when simple free propagation model is used. The paper concluded that the hop-count may not be an optimal metrics for the routing process and the routing metrics for MANETs should take into account the current state of the channel as well as the quality of the link.

Physical and Transport cross layer interactions: Power control can often influence the transmission rate of mobile nodes. The possibility to enhance multi-hop communication by balancing power control in the physical layer and congestion control in transport layer has been explored in [74]. The di stributive power control algorithm (JOCP) couples with original TCP protocol to improve end-to-end throughput and energy efficiency in the network. The key idea of JOCP is that during congestion periods nodes will try to transmit packets faster at the bottleneck links by updating their transmission power. More specifically, at each time slot the transmission power at a transmitter i will increase proportionally to its packet queuing delay λ and will decrease proportionally to its current power level $P_{i.}$ This analytical model proves the convergence of this coupled system to the global optimum of joint power and congestion control, for both synchronous and asynchronous implementations.

MAC and Transport cross layer interactions: The inability of TCP to distinguish between packet loss caused by congestion and packet loss by other factors (mobility of nodes, wireless link fluctuations) is the main cause of poor performance of TCP in

MANETs. While several proposals in literature attempt to solve the problem by modifying the MAC or the TCP in isolation, some solutions explore joint strategies at MAC and TCP layers. The problem of performance degradation of transport layer protocol due to congestion has been presented in [75]. The proposed cross-layer congestion control scheme (C3TCP) gives higher performance by gathering capacity information such as bandwidth and delay at the link layer. This method requires the introduction of an additional module within the protocol stack of the mobile node, able to adjust the outgoing data stream based on capacity measurements. Moreover, a proposal to provide optional field support to existing IEEE 802.11 protocol is also suggested, in order to support presented congestion control.

Joint optimal design for cross layer congestion control, routing and scheduling for adhoc wireless networks has been proposed [76]. The rate constraint and scheduling constraint are used based on flow variables and formulated resource allocation in networks with fixed wireless channel. The resource allocation problem has been decomposed into three sub problems: congestion control, routing and scheduling.

CHAPTER 3

Link Availability Model

Routing presents a challenge in MANET because mobility of nodes will cause frequent link breaks and hence frequent changes in topology due to mobility, leading to frequent route change. Thus QoS provisioning for application becomes a challenge [79]. When a link break occurs, the path has to be repaired either locally or a new path has to be discovered. During alternate route discovery after link break, packets will be dropped. This leads to wastage of the scarce node resources such as battery power.

In this chapter, an interpolation based approach has been proposed to predict the duration of availability of the current route. This approach aims to improve the Quality of Service (QoS) by predicting a link failure before its occurrence and routing the data packets through an alternate path, while nodes are moving around dynamically in the Mobile Adhoc Network. Availability of route is determined by availability of links between the nodes forming the route. Therefore, to estimate future availability of route, it is important to predict the availability of these links. Availability of a link between nodes depends on the mobility of nodes, energy consumption by the nodes, channel fading and shadowing, etc. However, mobility of the nodes is main contributing factor for link failures. We propose to use Newton divided difference interpolation for link prediction to estimate the availability of active link to the neighboring nodes. Based on this information, when link failure is expected between two nodes, proactively an alternate path is build up even before the link breaks. This reduces the data packet drops and hence the recovery time.

3.1 Link Prediction

In traditional mobile and wired-network routing algorithms, a change of path happens when a link along the path fails or another shorter path is found. A link failure is costly because multiple retransmission timeouts are required to detect the failure and after that a new path has to be found, leading to delay in restoration. Since paths fail so infrequently in wired networks, this is not an important issue. However, as routing protocols in mobile networks follow this model despite the significantly higher frequency of path disconnections that occur, QoS of route does get affected.

In this section, we propose a link prediction algorithm to predict the time after which an active link will break. This is done by estimating the time at which received signal strength of the data packets will fall below a threshold power. The received power level below the threshold indicates that the two nodes are moving away from each other's radio transmission range. The prediction of link break warns the source before the path breaks and the source can rediscover a new path in advance.

In this approach, three consecutive measurements of signal strength of packets received from the predecessor node are used to predict the link failure using the Newton divided difference method [81]. The Newton interpolation polynomial has the following generalized expression.

$$f(x) = f(x_0) + (x - x_0)f(x_0, x_1) + \cdots + \left(\prod_{i=0}^{n-1}(x - x_i)\right)f(x_0, x_1, \dots, x_n).$$

The received signal strengths of the three latest data packets and their time of occurrence are maintained by each receiver for each transmitter from which it is receiving. Using three received data packets' signal power strengths as P_1, P_2, $P_3$and the time when packets arrived as t_1, t_2, t_3 instants respectively and P_r as the threshold signal strength to be operative at the time t_p, one can predict t_p. We assume that at the predicted time t_p, when received power level reduces to threshold power, the link will break. The threshold signal strength P_r, is the minimum power receivable by the device. This is the power at the maximum transmission range. For example, WaveLAN cards have maximum transmission range of 250 meters in open environments in the 900 MHz band. The value of the threshold signal strength P_r is $3.65\text{x}10^{-10}$ Watts (e.g. characteristic of the WaveLAN card) [51]. The expected signal strength of the packets received can be computed as below, where Δ and Δ^2 are first and second divided differences respectively.

$$P_r = P_1 + (t_p - t_1)\Delta + (t_p - t_1)(t_p - t_2)\Delta^2. \tag{3.1}$$

$$P_r = P_1 + \frac{(t_p - t_1)(P_2 - P_1)}{(t_2 - t_1)} + (t_p - t_1)(t_p - t_2)\left(\frac{(P_3 - P_2)}{(t_3 - t_2)} - \frac{(P_2 - P_1)}{(t_2 - t_1)}\right)/(t_3 - t_1). \tag{3.2}$$

Let $A = ((P_2 - P_1)/(t_2 - t_1)),$ (3.3)

$$B = \left(\frac{(P_3 - P_2)}{(t_3 - t_2)} - \frac{(P_2 - P_1)}{(t_2 - t_1)}\right)/(t_3 - t_1). \tag{3.4}$$

The equation (3.2) becomes

$$P_r = P_1 + (t_p - t_1)A + (t_p - t_1)(t_p - t_2)B. \tag{3.5}$$

Rearranging equation (3.5),

$$Bt_p^2 + (A - Bt_1 - Bt_2)t_p + (P_1 - P_r - At_1 + t_1 t_2 B) = 0. \tag{3.6}$$

This is of the form

$$at_p^2 + bt_p + c = 0, \tag{3.7}$$

where $a = B$,

$b = (A - Bt_1 - Bt_2)$ and

$c = (P_1 - P_r - At_1 + t_1 t_2 B)$.

Therefore, the predicted time t_p at which link will fail is

$$t_p = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \quad (3.8)$$

Routing protocol needs time to setup a new or alternate path, thus a time parameter, critical time t_s , is introduced. The critical time t_s, should be sufficient enough to send error message to upstream node to source of the packet and for source to find a new route. The t_s should be just smaller than link break time t_p. After time t_s, the node enters into critical state and node should find an alternate route. When a link is expected to fail between nodes, the upstream node first attempts to find a route to the destination. If such route is not found within a fixed time called discovery period, a link failure warning is sent towards the sources whose flows are using this link. Source nodes can invoke the route discovery mechanism to setup restoration paths. At time t_s, the received power is sufficient for sending warning message to the upstream node and discovering an alternate path either by local route repair around the link which is going to break or by setting up new paths from sources. As two nodes move outwards, signal power of the nodes drops. Thus we define link break when nodes are first crossing the radio transmission range and broken links are repaired locally in k hops. The value of k is two, i. e. broken links can be repaired in two hops. The proposed local route repair procedure attempts to repair broken route locally with minimum control overheads for faster recovery.

3.1.1 Link Prediction Algorithm

Each time a data packet is received, the receiving node monitors the link with the following algorithm:

Algorithm 1: Link prediction algorithm

1. For each neighbour,
2. On receipt of a packet,
3. Update record of (received power, time) for last three packets,
4. If $((P_1 > P_2)$ and $(P_2 > P_3))$ then Prediction (),
5. Prediction ()
6. {
7. Estimate and update the t_p and update the t_s, when node enters into critical state, prior to link break
8. }
9. If (current time >=t_s)
10. {
11. Sent warning message to upstream node,
12. Sleep for fixed duration.
13. }
14. On receipt of repair message,
15. Set the route and link status as soon-to-be-broken,
16. Local route repair().

17. Local route repair()

18. {

19. Find path to next node n_j; //As shown in figure 3.1//

20. If (found a path in k hops within time)

21. Use this path for rerouting.

22. Else

23. Find path to destination D;

24. If (path is found)

25. {

26. Route the packet through new path,

27. Send message to sources to find shortest path.

29. }

30. }

1. At source:

2. {

3. New path discover message received,

4. Discover new path,

5. Redirect traffic through new path.

6. }

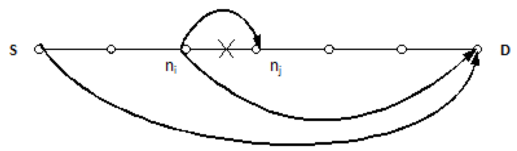

Figure 3.1 Local route repair

3.2 Simulation and Results

In this section, various simulation parameters, performance metrics and simulation results with its analysis have been covered.

3.2.1 Simulation Parameters

We have simulated AODV routing algorithm without (AODV) and with (AODVLP) link prediction to determine performance gain if any. NS-2 [82] has been used for this purpose. At the MAC layer, IEEE 802.11 protocol is used for simulation. Random waypoint model is used for representing nodes' mobility. Numerous simulations were run with same parameters and average of observed values was taken to reduce the estimation error. Two parameters viz. number of nodes and mobility pattern were varied in the sections 3.2.1 and 3.2.3. The detailed simulation parameters are mentioned in table 3.1.

Table 3.1 Simulation parameters for AODVLP

Traffic Pattern	Constant Bit Rate and TCP
Simulation Time	900 seconds
Total Connections	20, 25, 30, 35, 40 and 45
Traffic Load	4 packets/second
Max velocity	5,10, 15, 20, 25, 30 meters/second
Pause Time	10 seconds
Simulation Area	1500m by 300m
Total Nodes	25, 50, 75, 100 and 125
Data Packet Size	512 bytes

3.2.2 Performance Metrics

The performance of the model is evaluated in terms of number of route failures, packet delivery ratio and average end-to-end delay as a function of number of nodes and node mobility. The number of nodes was varied from 25 to 125 and node velocity from 5 to 30 meters/second. At a time, one variable was changed and other was kept constant. When the parameters are kept fixed, they are assumed to take the following values — network size = 50 nodes and node velocity = 5 meters/second.

In the sections 3.2.1 and 3.2.2, constant bit rate (CBR) sources are assumed. In the section 3.2.3, TCP sources have been assumed. The packet generation rate is taken as 4 packets/second for all kind of sources in the simulations.

Packet delivery ratio is the ratio of the data packets delivered to the destination to those generated by either CBR or TCP sources. The higher the value better is the performance. The IP packets generated due to retransmissions in TCP are counted as separate data packets for the purpose of packet delivery ratio. For example, A data packets are sent from TCP source resulting in A+A' packets, where A' packets are due to retransmissions. B packets are received then packet delivery ratio will be $B/(A+A')$.

Average end-to-end delay of data packets includes all possible delays caused by buffering during route discovery, queuing at interface queue, retransmission delays at MAC layer, propagation and transfer time.

Number of route failures is the number of routes which failed during the simulation time.

3.2.3 Simulation Results and Analysis

In this section, simulations results are obtained with UDP/CBR sources in the sections 3.2.3.1, 3.2.3.2 and with TCP sources in the section 3.2.3.3. Simulations for energy related metrics are included in section 3.2.3.2.

3.2.3.1 Simulations with CBR traffic

The simulation results are obtained for AODV and AODVLP for CBR sources. The network size is varied and other simulation variables are kept constant with pause time as 10 seconds and velocity as 5 meters/second, to get the results shown in figures 3.2, 3.3, 3.4 and 3.5. Figure 3.2 shows variation of route failures with increasing network size. Results show that route failures are much less in AODVLP as compared to AODV. It happens because in AODVLP, alternative routes are discovered in advance much before the link failure, and messages are delivered through alternative route. However, AODVLP and

AODV both give more route failures with increase in node density because nodes tend to switch over to more optimal routes. The switch over happens more frequently due to availability of more route in the topology. Intentional switchovers are also counted as route failures.

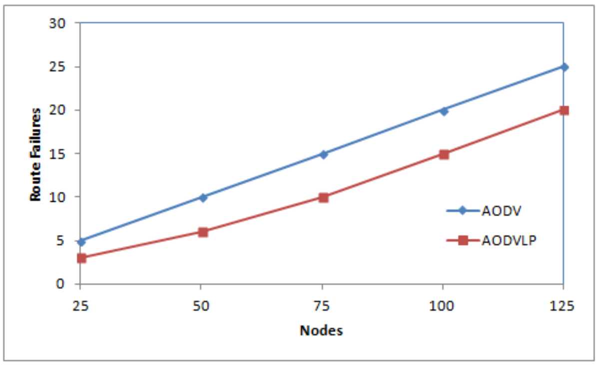

Figure 3.2 Route failures vs nodes

Figure 3.3 shows variation of packet delivery ratio with increasing network size. Results show that packet delivery ratio is better in AODVLP as compared to AODV. It happens because in AODVLP, alternative routes are discovered before the route failures, and more data is successfully delivered to the destination. However, AODVLP and AODV give smaller delivery ratio as network size increases, since it has more route failures as shown in figure 3.2 which results in packet drops. Increased node density causes more contentions and collisions due to more neighboring nodes in the vicinity. Increase in average RTS collisions per node are observed, as shown in figure 3.4. Due to more collisions, the delivery ratio decreases by retransmitting the packets more than once.

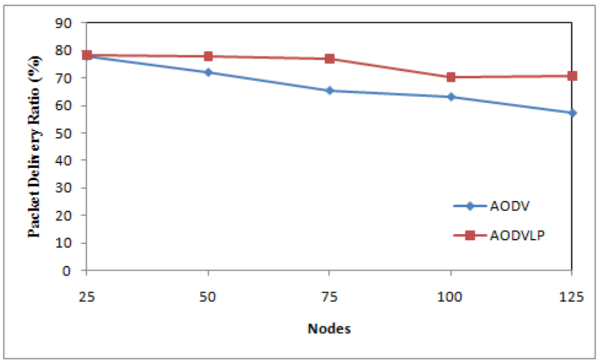

Figure 3.3 Packet delivery ratio vs nodes

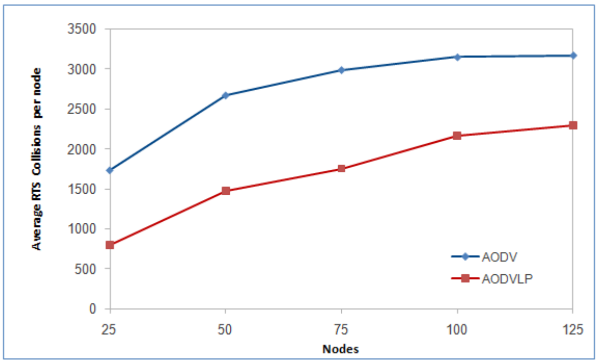

Figure 3.4 Average RTS collisions per node vs nodes

The end-to-end delay is an average of difference between the time a data packet is generated by an application and the time the data packet is received at its destination. Figure 3.5 shows decrease in end-to-end delay in AODVLP as compared to AODV due to advance route discovery in case of route failures. However, end-to-end delay increases with increase in the network size in AODVLP and AODV because high node density increases collisions, as shown in figure 3.5, which results in retransmission of packets.

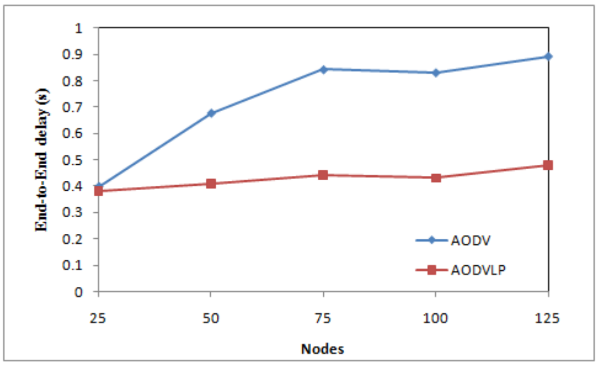

Figure 3.5 End-to-end delay vs nodes

The velocity is varied in discrete steps as 5, 10, 15, 20, 25 and 30 meters/second for a fixed network size of 50 nodes and pause time of 10 seconds in figures 3.6, 3.7, 3.8 and 3.9. Figure 3.6 shows variation of route failures with increasing node velocity. From these results, it is quite evident that AODVLP gives fewer route failures than AODV because link prediction model helps in discovering the alternative routes in advance before a link failure, and messages are delivered through the alternative routes. However, for AODVLP and AODV, route failures increase with increase in node velocity. With fast mobility, more links and thus more routes break.

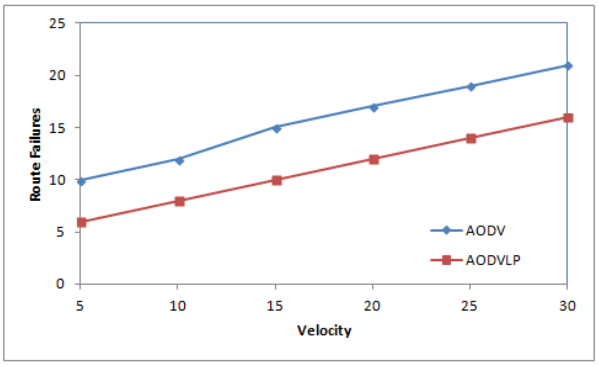

Figure 3.6 Route failures vs node velocity

Figure 3.7 shows variation of packet delivery ratio with increasing node velocity. Results show that packet delivery ratio is better in AODVLP as compared to AODV. It happens because in AODVLP, alternative routes are discovered before the route failures, and more data is successfully delivered to the destination. The result also shows that the packet delivery ratio decreases as the node velocity increases because faster mobility of nodes causes more route failures as shown in figure 3.6. Further, more route failures result in packet drops and thus low packet delivery ratio.

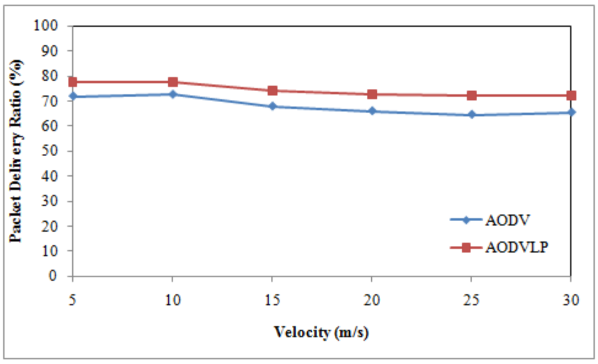

Figure 3.7 Packet delivery ratio vs node velocity

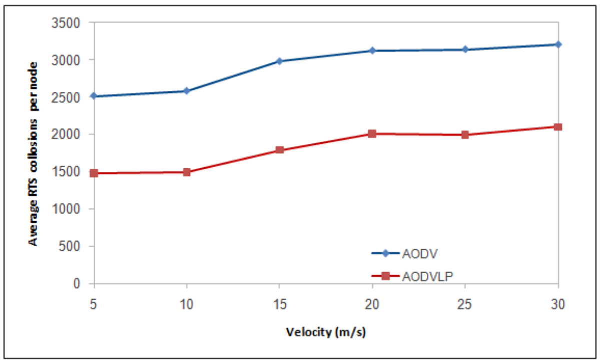

Figure 3.8 Average RTS collisions per node vs node velocity

Figure 3.9 shows increase in end-to-end delay with increase in node velocity. The results show that AODVLP outperforms AODV significantly with increase in node velocity. We observe that the end-to-end delay increases when node velocity increases.

The result shows that by increasing the velocity of nodes, delay increases because more route failures occur for fast moving nodes. Therefore, overheads of new route discovery lead to increase of the end-to-end delay.

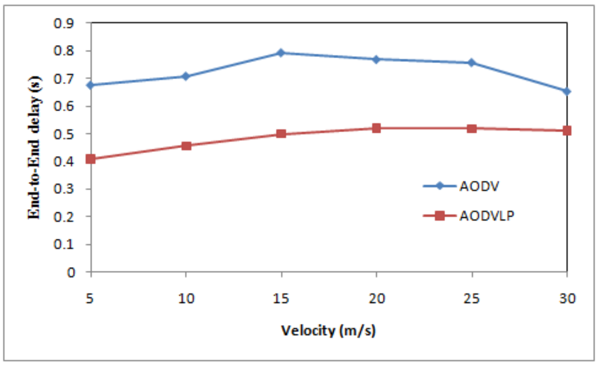

Figure 3.9 End-to-end delay vs node velocity

3.2.3.2 Energy Simulations

In this section, we have explained simulation parameters and the simulation results for the study of energy consumption of AODV and AODVLP schemes. We have compared throughput, energy consumption per successful transmission of AODVLP and AODV schemes. We have observed their performance behavior by varying network load and the node density within a given area. Network load is the rate of generation of packets in the network and throughput is calculated as number of kilobytes data received by the destination node per second.

The packet generation rate is varied for a fixed network size of 50 nodes, velocity of 5 meters/second and pause time of 10 seconds in figures 3.10 and 3.11. The simulation results are obtained for AODV and AODVLP. Figure 3.10 shows the comparison of the throughput of AODV and AODVLP. It shows that AODVLP achieves higher throughput compared to AODV. It happens because in AODVLP, alternative routes are discovered in advance before a link failure, and delivers a message through alternative route. However, AODV and AODVLP give increasing throughput as packet generation rate increases and saturate by remaining constant after a particular point. As at low packet generation rate, less number of packets would be contending for the transmission and at higher network loads, more data can be delivered per second, therefore throughput increases linearly and saturates thereafter.

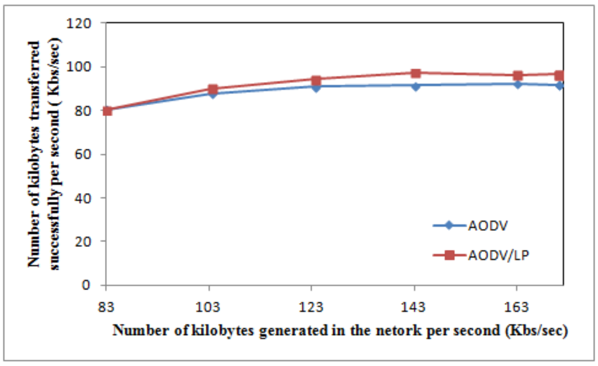

Figure 3.10 Successfully data transmission rate vs traffic generated rate

Figure 3.11 shows variation of energy consumed per successful communication of 1 kilobyte of data with increasing packet generation rate. Results show that power consumption per successful communication of 1 kilobyte of data is lesser in AODVLP as compared to AODV. It happens because in AODVLP link successes are observed to avoid packet drops and thus, avoiding retransmissions of packets. However, AODV and AODVLP give increasing average energy consumption as network load increases, since more packets are generated in the network and thus these packets are send to the destinations therefore, more energy is consumed in successful communication of these packets.

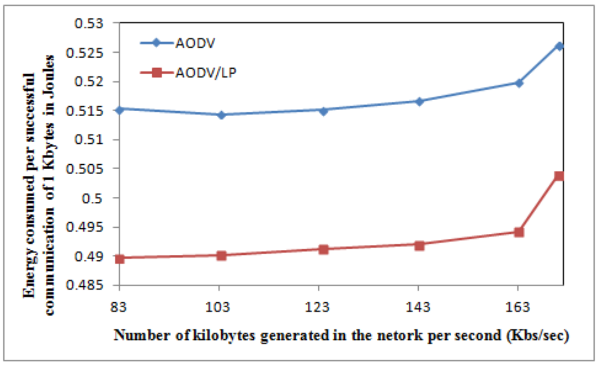

Figure 3.11 Average energy consumption (in Joules) per communication of 1Kbyte of data vs traffic generated rate

The density of the nodes is varied and other simulation variables are kept constant with pause time as 10 seconds and velocity as 5 meters/second in figures 3.12 and 3.13. Figure 3.12 shows that in AODV and AODVLP, the throughput per node is decreasing with increase in number of nodes because increase in node density increases collisions and contention. At very low density, the AODV and AODVLP give throughput per node is more because contention and collisions are lesser. At higher node density, contention and collisions are more leading to lesser throughput per node.

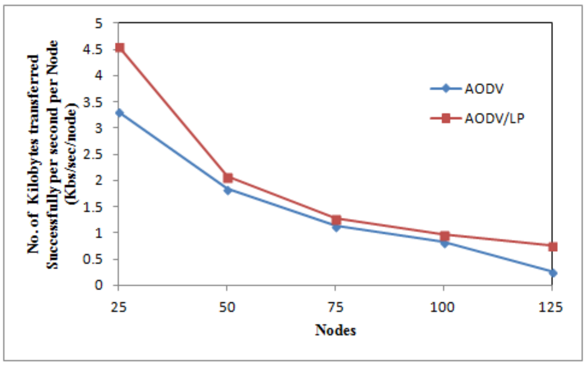

Figure 3.12 Throughput per node vs nodes

Figure 3.13 shows AODVLP consumes lesser energy as compared to AODV and therefore more packets can be transmitted in lesser energy. The energy consumption increases in case of both the schemes as the node density increases. Increased node density causes more contentions and collisions. But the energy consumption of the AODVLP is lower throughout the density variation thereby making it the scheme, which consumes lesser energy.

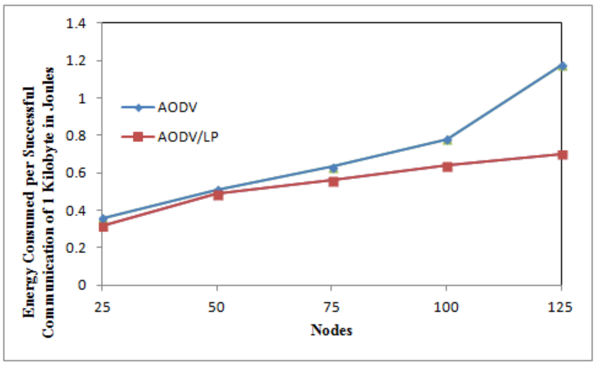

Figure 3.13 Energy consumption per communication of 1 kilobyte data vs nodes

3.2.3.3 TCP Simulations

The simulation results are obtained for AODV and AODVLP with TCP sources. The performance metrics are packet delivery ratio and end-to-end delay. As seen from figures 3.14 and 3.17, AODVLP offers better end-to-end delay performance than AODV and comparable packet delivery ratio in both AODVLP and AODV. The network size is varied with fixed pause time as 10 seconds and velocity as 5 meters/second in figures 3.14 and 3.15.

From figures 3.14 and 3.15, it can be seen that AODVLP offers slightly better end-to-end delay performance than AODV and both have nearly identical packet delivery ratio with increased node density. The packet delivery ratio in AODV and AODVLP are comparable and remains low, as shown in figure 3.14 because of feedback property of TCP, which deceases the rate of packet generation with increasing estimated round-trip time and vice versa (rate limiting property of TCP). However, packet delivery ratio increases slightly in both AODVLP and AODV as node density increases. This happens because packet delivery ratio is relatively low, with TCP as compared with CBR traffic in both AODV and AODVLP with increased node density.

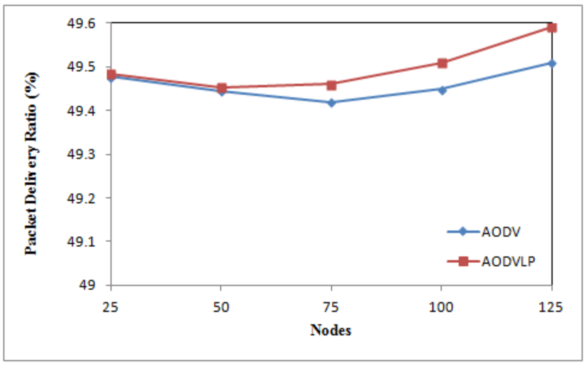

Figure 3.14 Packet delivery ratio vs nodes

Figure 3.15 shows decrease in end-to-end delay in AODVLP as compared to AODV due to advance route discovery in case of route failures. However, end-to-end delay increases with increase in the network size in AODVLP and AODV because high node density increases contention and collisions, which results in retransmission of packets. As the number of nodes increases in the vicinity, increases the contention in the wireless physical channel because the simulation model uses only a single channel (frequency) for communication between nodes. This in turn increases the probability of collision of the control (RTS/CTS/ACK) packets at the MAC 802.11 (CSMA/CA) layer. The collisions require the transmitting nodes to perform an exponential back-off, which greatly reduces link utilization and effective bandwidth. Hence, in such highly inter-connected networks, the end-to-end delay performance degrades with increase in node density.

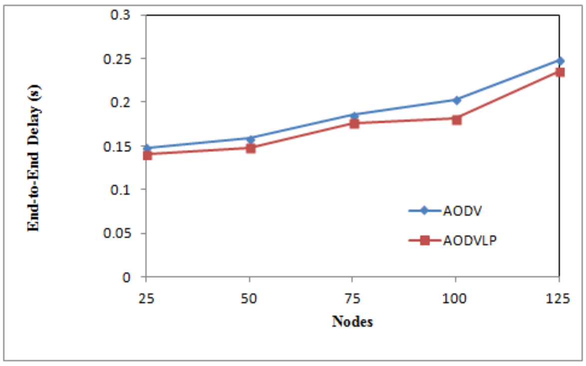

Figure 3.15 End-to-end delay vs nodes

The velocity is varied as 5, 10, 15, 20, 25 and 30 meters/second for a fixed network size of 50 nodes and pause time of 10 seconds in figures 3.16 and 3.17. Figure 3.16 shows variation of packet delivery ratio with increasing node velocity. Results show that packet delivery ratio is better and comparable in AODVLP as compared to AODV. It happens because in AODVLP, alternative routes are discovered before the route failures and more data is successfully delivered to the destination and packet delivery ratio remains low in AODVLP and AODV both due to feedback property in TCP. The result also shows that the packet delivery ratio decreases as the node velocity increases because faster mobility of nodes causes more route failures. Further, more route failures result in packet drops and thus low packet delivery ratio.

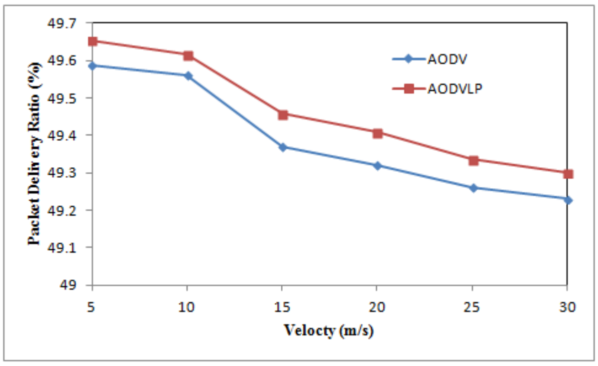

Figure 3.16 Packet delivery ratio vs node velocity

Figure 3.17 shows increase in end-to-end delay with increase in node velocity. The results show that AODVLP outperforms AODV significantly with increase in node velocity. We observe that the end-to-end delay increases when node velocity increases. The result shows that by increasing the velocity of nodes, delay increases because more route failures occur for fast moving nodes. Therefore, overheads of new route discovery lead to increase of the end-to-end delay. This shows that the method proposed for anticipating link breaks can result in overall substantial performance gain.

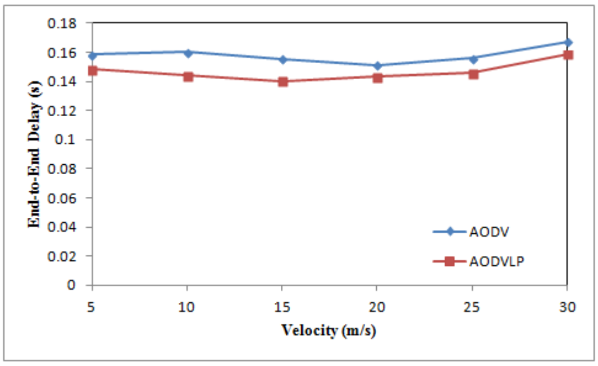

Figure 3.17 End-to-end delay vs node velocity

3.3 Summary and Future Work

In this chapter, we have proposed AODV routing protocol with link prediction for adhoc networks. A prediction function that predicts link breaks based on signal strength of the three consecutive received packets and a threshold signal strength, has been presented. The AODV can thus proactively initiate repair process even before the occurence of failure.

The performance of the proposed AODV with link prediction has been evaluated and compared with AODV using simulations. The simulation results show that the proposed algorithm performs well and results in lower end-to-end delay and higher packet delivery ratio due to local and proactive repair processes, and therefore leading to improvement of the Quality-of-Service.

AODVLP can be further improved by limiting overhead of unnecessary control messages. The suitability of AODVLP for real-time traffic needs to be further studied by testing it with smaller sized CBR packets at a higher packet generation rates. The performance of other routing algorithms can also be evaluated by incorporating link prediction. One can also explore better link prediction methods.

CHAPTER 4

Dynamic Power Control Wireless Adhoc MAC Protocol

In mobile adhoc networks, the nodes cooperate with each others in forwarding the packets generated by a source to the destination through the network. This means that the throughput is not limited only by the available channel capacity, but also by the forwarding load imposed on intermediate nodes. The total capacity of a network grows with the area it covers. Network coverage can be increased by efficient spatial reuse of the spectrum. However, this effect could seriously limit the network throughput. On the other hand, the mobile adhoc networks experience more collisions due to hidden node case as the nodes overlap successively in space. The increase in the number of collisions degrades the network throughput and leads to lower throughput. In other way it makes hidden and exposed terminal problems more acute in such networks and balancing between these two problems is more complex and challenging.

Researchers have proposed many power control schemes for mobile adhoc networks to reduce the energy consumption for increasing life- time and capacity of the nodes and thus the networks. However, these schemes may increase energy consumption and degrade the throughput due to the decrease in carrier sensing range or increase in interference range. The carrier sensing range of the IEEE 802.11b std. is always at maximum. However, increasing the carrier sensing range to maximum reduces the level of the spatial reuse. This drawback affects the overall throughput and hence energy consumption especially in case of mobile adhoc networks. Since some nodes of the multi-hop route in the maximum carrier sensing range can also transmit data successfully to its corresponding receiver without affecting the first ongoing transmission. Therefore, the design of an efficient energy conservation protocol in mobile adhoc networks requires considering power control to improve the network performance.

The nodes in mobile adhoc networks are mobile, smaller in size and battery powered. There are various issues in these types of networks. Due to the mobility, the routing paths have to be updated all the time. Since nodes are wireless, factors such as multiple-access, signal fading, noise and interference can cause the effective throughput to be much smaller in the wireless networks. Since the nodes are battery powered, power consumption is an important issue. In this network even other nodes act as intermediate nodes in forwarding a packet, hence if one node goes down the overall network capacity reduces drastically.

In this chapter, we have proposed DPCP power control protocol in which all packets RTS, CTS, DATA and ACK are sent at optimum power level which is required for the destination node to receive correctly. The goal of the proposed scheme is to save power and maximize throughput in mobile adhoc networks.

The rest of this chapter is organized as follows: The proposed DPCP protocol is explained in section 4.1. Section 4.2 presents simulation results and comparison between protocols. Finally, section 4.3 concludes the work presented in this chapter.

4.1 Dynamic Power Control Wireless Adhoc MAC Protocol (DPCP)

We have proposed DPCP power control protocol in which all packets RTS, CTS, DATA and ACK are sent at optimum power level which is required for the destination node to receive correctly. The proposed DPCP power control protocol which simultaneously improves the throughput and yields energy saving. The simulation results show that the proposed power control protocol achieves reduction in energy consumption and improvement in the throughput compared to the IEEE 802.11b std.

4.1.1 Proposed protocol basics

In this MAC protocol, all packets RTS, CTS, DATA and ACK are sent at optimum power level which is required for the destination node to receive correctly. The optimum transmission power computed based on formula (4.4), which is defined by the ongoing transmissions such that ongoing communications may not hampered. We have used 10 discrete power levels for the transmission of RTS, CTS, DATA and ACK packets. The header fields of the packets RTS, CTS, DATA and ACK are modified to incorporate the transmission power levels of the respective packet; this is in accordance to the other power aware protocols. Thus when a node receives such packet, it gets the transmission power level P_t and the received power level P_r is calculated by the physical layer and the value is sent to MAC layer. Every node knows the minimum decoding power at which the packet can be decoded properly. From these three parameters we can get the minimum transmission power required so that the packet is properly decoded at the receiver.

Each node will maintain table which will contain the minimum transmit power level required so that the destination node will be able to decode the packet successfully.

Hence, the table will have two columns; one will be the MAC address of the destination node and the other will the power level. This table is OPTIMUM POWER TABLE.

4.1.2 Model description

The IEEE 802.11b std. is reliable MAC protocol. When a sending node transmits RTS, CTS, DATA and ACK packets, every exposed node receives the packet at received signal strength. The received signal strength, P_r at receiver using two ray propagation model is:

$$P_r = P_t G_t G_r [\frac{\lambda}{4\pi d_{ij}}]^2. \tag{4.1}$$

Where λ is the wavelength of carrier, d_{ij} is the distance between sender and receiver. G_t and G_r are unity gain of transmitting and receiving omni directional antennas respectively. The power P_t is the transmit power of the packet. The header fields of the packets RTS, CTS, DATA and ACK are modified to incorporate the transmission power level of the respective packet.

Thus when a node receives such packet, it gets the transmission power level P_t, the received power P_r is calculated by the physical layer and the value is send to MAC layer. Every node knows the minimum decoding power P_{decode} at which the packet can be decoded properly. Thus we get the desired optimum transmission power required so that packet is properly decoded at the receiver is given by the corresponding formulas as given below.

$$P_{tmin} = \frac{P_{decode}}{G_t G_r} [\frac{4\pi d_{ij}}{\lambda}]^2 * c. \quad (4.2)$$

However, we do not have information about distance [24] between two nodes then we can find out transmission power by the equation

$$P_{tmin} = \frac{P_{decode} * P_t^{'} * C}{P_r^{'}}. \quad (4.3)$$

$$P_{opt} \geq P_{tmin} \quad (4.4)$$

Where, P_{opt} is the discrete level greater than P_{tmin}, $P_t^{'}$ and $P_r^{'}$ are the transmission and received powers of the previous packet from that receiver to sender, respectively. C is a constant equal to 1.05 to compensate for the interference and noise.

In this scheme, the received signal strength information obtained and calculated at the physical layer and then, is passed to the MAC layer for data transmission. The optimum transmit power is computed using equation (4.4). This P_{tmin} is stored at each node in the table against the destination. In order to get the optimum transmit power, the header fields of packets RTS, CTS, DATA and ACK are modified to incorporate the transmit power level of the respective packets. Thus, when a node receives such packet, it gets the transmission power level P_t, the received power P_r is accessed from the physical layer and the calculated transmit power is passed to the MAC layer.

The node sending RTS inserts transmit power as an extra field in it so that the receiving node can tune to this power while sending its CTS packet. Subsequently by using the optimum transmit power level, the DATA packets from sender and ACK packet from receiver can also be transmitted.

4.1.3 Proposed protocol description

The proposed power control protocol works in the following steps:

- Transmitter sends a RTS with the optimum transmit power level including the power level in the header of the RTS.
- Receiver decodes the RTS, finds transmit, observes receive power level and calculates optimum transmit power using equation (4.4). The receiver attaches the transmit power to the CTS packet and transmits CTS using the optimum power level.
- The transmitter extracts the transmit power level, observes receive power level and calculates optimum transmit power level. The transmitter adds optimum transmit power to the DATA header and sends the DATA packet at this power level.
- The receiver sends ACK using the optimum power level.

4.1.4 Proposed protocol algorithm

In power control algorithm, $P_t[L]$ is the set of power levels used for the transmission, where L is an integer varies from 1 to 10. The transmit power $P_t[L]$ is the maximum power level and the number of power levels in the set is 10.

A. Transmitter:

Step 1: Let $P_t[L] = 2.818$.

Step 2: Check the optimum power table at the transmitter node for the receiver node address and its stored optimum transmit power value P_{tt}.

Step 3: If node entry is available, then $P_t[L] = P_{tt}$ else $P_t[L] = 2.818$.

Step 4: Add this power value in RTS header and send RTS with this power level $P_t[L]$.

Step 5: Receive CTS packet, observe its received power P_r and extract transmit power. The node calculates optimum transmit power for DATA packet. Update optimum power table.

Step 6: Add the power level in the DATA packet header and send the DATA packet at optimum transmit power level.

Step 7: Receive ACK.

Step 8: End.

B. Receiver:

Step 1: Receive RTS.

Step 2: Observe the receive power, extract the transmit power and then calculate the optimum transmit power for the CTS packet. Update optimum transmit power table with power level $P_t[L]$.

Step 3: Insert the optimum transmit power in the CTS header and send the CTS packet at the same power level.

Step 4: Receive DATA packet.

Step 5: Include the optimum power level in the ACK packet header and send the ACK packet this transmit power level.

Step 6: End.

4.2 Simulation and Results

We have evaluated performance of the DPCP through simulations. We have simulated IEEE 802.11 and dynamic power control protocol (DPCP) using ns-2 [82]. Numerous simulations were run with same parameters and average of observed values was taken to reduce the estimation error.

4.2.1 Simulation Parameters

Two-ray radio propagation model is used. We use 10 transmit power levels, 1mW, 2 mW, 3.45 mW, 4.8 mW, 7.25 mW, 10.6 mW, 15 mW, 36.6 mW, 75.8 mW and 281.8 mW, which roughly corresponds to the transmission ranges of 40 m, 60 m, 80 m, 90 m, 100 m, 110m, 120 m, 150 m, 180 m, and 250 m respectively. The detailed simulation parameters are mentioned in table 4.1. Two parameters viz. network load and density – number of nodes in the area were varied in the simulations. Network load is the rate of generation of packets in the network.

s

Table 4.1 Simulation parameters for DPCP

Traffic Pattern	**Constant Bit Rate**
Simulation Time	900 seconds
Total Connections	20, 25, 30, 35, 40, 45 and 50
Packet size	512 Bytes
Velocity	5 meters/second
Pause Time	10 seconds
Simulation Area	1500m by 300m
Total Nodes	25, 50, 75, 100, 125 Nodes

4.2.2 Performance Metrics

The performance of protocols has been evaluated in terms of throughput and energy consumption as function of number of nodes and packet generation rate. Constant bit rate (CBR) sources are assumed in the simulation.

Throughput is the number of kilobytes transferred successfully by the sender to the receiver successfully.

Energy consumed (in Joule) per 1 kilobyte data delivered is calculated as the total amount of transmitting and receiving energy consumption over all flows divided by the total data delivered by all the flows. The energy consumption of all the packets RTS, CTS, DATA and ACK are considered.

4.2.3 Simulation Results and Analysis

The simulation results are obtained for IEEE 802.11 and DPCP. Figure 4.1 shows the comparison of the throughput of IEEE 802.11 and DPCP. It shows that DPCP achieves higher throughput compared to IEEE 802.11 schemes. This is because DPCP uses smaller carrier sensing range compared to IEEE 802.11, therefore large number of nodes can transmit concurrently. However, DPCP gives increasing throughput as packet generation rate increases and saturate and remains constant after a particular point. As at low packet generation rate, less number of packets would be contending for the transmission, therefore throughput increases linearly and saturates at higher packet generation rate.

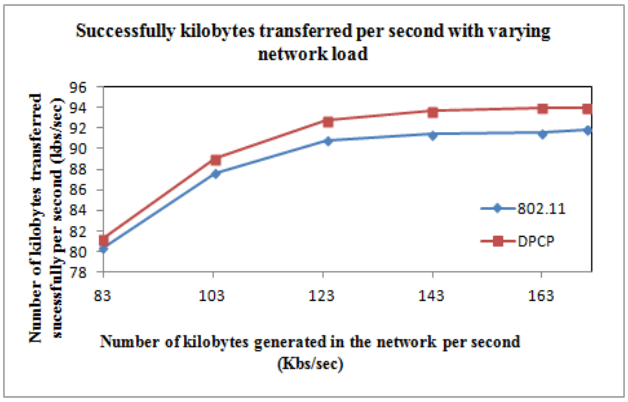

Figure 4.1: Successfully data transmitted vs traffic generated rate

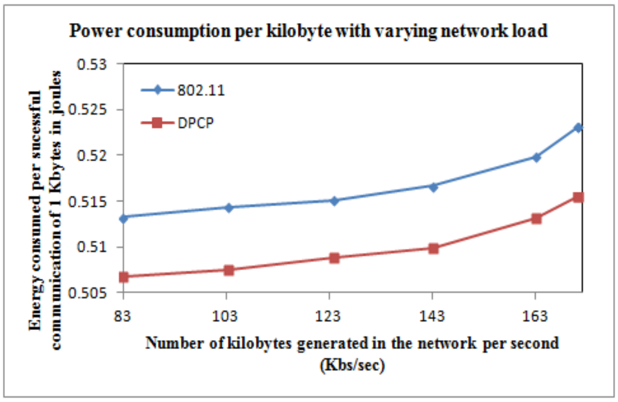

Figure 4.2: Average energy consumption (in Joule) per communication of 1kilobyte of data vs traffic generated rate

Figure 4.2 shows variation of energy consumed per successful communication of 1 kilobyte of data with increasing packet generation rate. Results show that power consumption per successful communication of 1 kilobyte of data is lesser in DPCP as compared to IEEE 802.11. It happens because in DPCP packets RTS, CTS, DATA and CTS are sent at optimum power, which is lesser than maximum transmit power. However, DPCP and IEEE 802.11 give increasing average energy consumption as network load increases This happens because reduction in transmit power also reduces the number of deferring nodes, and thus, more data can be delivered per joule.

In the figure 4.3, we see that the throughput per node decreases in both schemes with increase in node density because of contention and collisions of the packets. The throughput in DPCP is better than IEEE 802.11 std because of concurrent transmission of packets due to spatial reuse of the channel. This happens as RTS, CTS, DATA and ACK are transmitted at lower power in DPCP scheme.

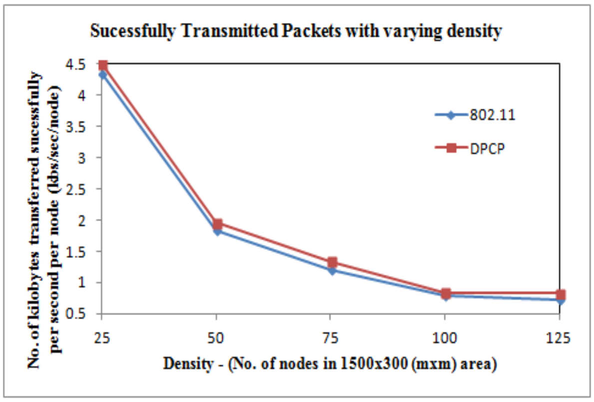

Figure 4.3: Successfully 1 kilobyte of data transmitted vs density

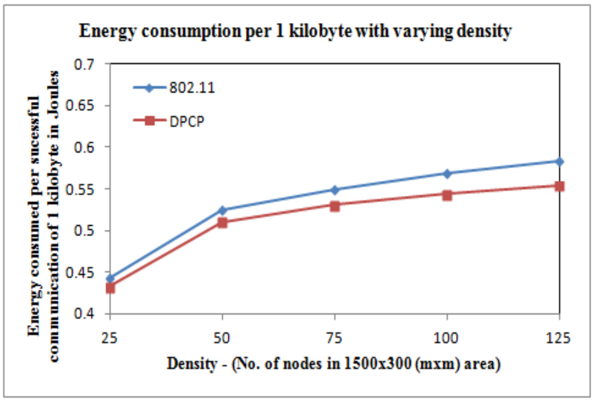

Figure 4.4: Average energy consumption (in Joule) per communication of 1kilobyte of data vs density

In figure 4.4, we observe that average energy consumption in communication of 1 kilobyte of data is lesser DPCP than IEEE 802.11 scheme as RTS, CTS, DATA and ACK are transmitted at lower power. As the node density increases, energy consumption per successfully transmitted 1 kilobyte of data increases in both schemes. This happens because contention and collision of the packets increases with increased node density results in increased energy consumption.

4.3 Summary and Future work

We have proposed and evaluated the performance of a new power control protocol for wireless adhoc networks called Dynamic Power Control protocol (DPCP). This protocol transmits all the packets with the optimum transmission power. The optimum power is found based on reducing the carrier sensing range to increase throughput and reduce energy consumption. This reduces the number of unnecessary back-off nodes and allows successful concurrent transmissions to take place in the neighborhood of a receiver. We have compared the performance of the DPCP scheme with IEEE 802.11 std. We investigated its performance under different network loads and node density. The simulation results showed that the DPCP scheme achieved more kilobytes of data transferred per second and reduction in energy consumed per successful communication of 1 kilobyte data in joules. This means that the DPCP scheme can achieves a high reduction in the energy consumption. On the other hand, the simulation results also indicate that the DPCP scheme improves the network throughput compared to IEEE 802.11 std. The DPCP protocol is mainly designed to save energy and improve the throughput.

CHAPTER 5

Cross Layer Design for Power Control and Link Availability

Frequent changes in network topology due to mobility and limited battery power of the mobile devices are the key challenges in the mobile adhoc networks. The depletion of power source may cause early unavailability of nodes and thus links in the network. The mobility of nodes causes frequent routes breaks and adversely affects the required performance of the applications.

In order to be mobile, untethered connectivity using wireless interfaces need to be present with every node in the network. Usually mobile nodes will depend on battery power for their operations. It is desirable to minimize the power consumption in these nodes. Further, this problem is important as once the battery of the node is exhausted, it cannot transmit as well as receive any data. It dies resulting in impact on network connectivity since in adhoc networks, even intermediate nodes are important to maintain connectivity. As soon as one of the intermediate nodes dies, the whole link has to be formed again. This leads to large amount of delay, waste of scarce node resources like battery power thereby hampering the throughput of the whole system. Further, mobility presents the challenges in the form of continuously variable topology and thus requiring a complex and energy efficient routing mechanisms.

Wireless networks will be used mostly by personal communication devices which people can carry with them. These small, always connected personal devices will lead to new applications. For running most of these applications on resource limited devices, one needs efficient networking stack in the mobile devices. Conventionally to simplify the complex task of handling network connectivity, layered architecture had been used. To further improve the performance, the concept of layered software components is now being broken by also allowing layers to access data structures from non-immediate layers. This approach is popularly known as cross layer optimization.

Quality of Service in MANETs will imply guaranteed delivery of packets corresponding to the specific flows at higher priority so as to satisfy loss and delay performance requirements. In MANETs, node functions using remaining battery power, availability of which can vary widely across the nodes. The nodes may be mobile, thus the links in the optimal path from source to destination may break either due to mobility or less battery power. Thus providing QoS guarantees with highly unreliable links, need fast or even proactive routing recovery, alongwith transport and application layer optimization, which may start even before the link failure finally happens. Thus the measurements at data link layer and MAC layer need to be used at the network, transport and application layers to avoid wastage of transmitted power due to transmission of data frames which are of no use due to link failure.

We have proposed a cross layer design for power control and link availability prediction (DPCPLP) in mobile adhoc networks that provides a combined solution for power conservation as well as link availability. The simulation results show that the proposed cross layer design improves the throughput, packet delivery ratio by prior prediction of link breaks and initiating the route repair. It also reduces average communication interruption time, routing overheads, end-to-end delay and power consumption. Thus, this shows that the proposed cross layer design increases network and nodes' lifetime and capacity.

This chapter has been organized in three sections. Section 5.1 discusses the details of proposed power control to reduce the power consumption and a model to estimate the link availability. Section 5.2 covers simulation results and analysis including simulation parameters which have been considered, performance metrics and the simulation results. Section 5.3 summarizes the work.

5.1 Cross Layer Power Control and Link Availability Prediction

We have proposed a cross layer design for the dynamic power control protocol and link prediction (DPCPLP) that provides a combined solution for power conservation as well as link availability. This combines the effect of optimum transmit power and received signal strength based link availability estimation with AODV routing protocol using cross layer approach. This method proposes to use optimum transmit power for transmitting the packets to a neighboring node to increase the battery life of adhoc nodes and received signal strength based link prediction to increase the availability of the links. The transmit power and received signal strength of the packets are cross-layer interaction parameters to provide the combined solution for power conservation and reliable route formation with increased availability of links and thus the routes amongst sources and destinations. The cross layer interactions are between non-adjacent layers in the protocol stack. It improves the throughput, packet delivery ratio by prior prediction of link breaks and initiating the route repair. It also reduces communication interruption time, routing overheads, end-to-end delay and power consumption by use of cross layer interaction.

Figure 5.1 shows cross layer interactions used in DPCPLP are between physical and network layers. The received signal strength is used by network layer to initiate the process to find the new route.

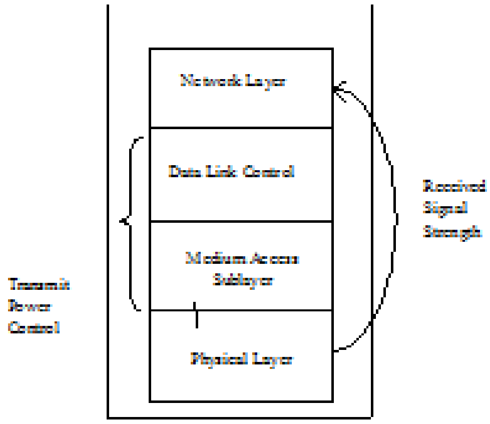

Figure 5.1: Cross layer interactions at node

Cross layer based approach for link availability prediction (DPCPLP) increases networks and nodes' lifetime and capacity by combining the effect of optimum transmit power in transmitting RTS, CTS, DATA and ACK packets and estimation of link availability time and further, formation of the path prior to the link break to support the Quality of Service (QoS) requirements of applications.

1) **Power control**: At the MAC layer RTS, CTS, DATA and ACK are sent at optimum transmit power level just adequate to sustain a good quality communication. The estimation is done dynamically based on received signal strength of RTS, CTS,

DATA and ACK packets between links and accordingly, the sender can adjust it's transmit power.

2) **Link availability**: Using received signal strength of packets from physical layer, link availability time can be estimated and the prediction of link break warns the upstream nodes and sources before the path breaks and either upstream nodes or sources can rediscover a new path in advance for forwarding the packets.

5.1.1 Power control

To maximize the battery life of mobile nodes, we have proposed the Dynamic Power Control Protocol (DPCP) part at MAC layer. This protocol is based on Adaptive Power Control MAC protocol in such a way that the overall transmitted power is less and hence battery consumption is less.

At MAC layer, RTS, CTS, DATA and ACK are sent at the optimum power. The header fields of the packets RTS, CTS, DATA and ACK contain the transmission power level which can be used to compute optimum power to send a packet.

The IEEE 802.11std is reliable MAC protocol. When a sending node transmits RTS, CTS, DATA and ACK packets, every exposed node receives the packet at received signal strength. The received signal strength, P_r at receiver using two ray propagation model is:

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi d_{ij}})^2. \tag{5.1}$$

Where λ is the wavelength of carrier, d_{ij} is the distance between sender and receiver. G_t and G_r are the gain of transmitting and receiving omni directional antennas respectively. The power P_t is the transmit power of the packet. The header fields of the packets RTS, CTS, DATA and ACK are modified to incorporate the transmission power level of the respective packets.

Thus when a node receives such packet, it gets the transmission power level P_t, the received power P_r is calculated by the physical layer and the value is send to MAC layer. Every node knows the minimum threshold power $P_{threshold}$ at which the packet can be decoded properly. Thus we get the desired minimum transmission power required so that packet is properly decoded at the receiver.

$$P_{tmin} = \frac{P_{threshold}}{G_t G_r} (\frac{4\pi d_{ij}}{\lambda})^2 * c. \qquad (5.2)$$

However, we do not have information about distance [24] between two nodes. We can find out optimum transmission power by the equation

$$P_{tmin} = \frac{P_{threshold} * P_t^{'} * C}{P_r^{'}}. \qquad (5.3)$$

$$P_{opt} \geq P_{tmin}. \qquad (5.4)$$

Where, P_{opt} is the optimum transmission power and is discrete level greater than P_{tmin}, $P_t^{'}$ and $P_r^{'}$ are the transmission and received powers of the previous packet from that receiver to sender, respectively. C is a constant equal to 1.05 to compensate for the interference and noise.

Each node will maintain table which will contain the optimum transmit power level required so that the destination node will be able to decode the packet successfully and can initiate the process for link successes. The table will have two columns, one will have MAC address of the destination node and the other will be the power level. This table will be known as the OPTIMUM POWER TABLE. This table is small as it contains entries only of the neighbours. The Optimum Power Entry format is shown in figure 5.2.

Node	OPTIMUM TRANSMIT

Figure 5.2: Format of Optimum Power Table

In this cross layer design, the receiving node limits the optimum transmit power to a level just adequate to sustain good quality communication and start the process for prediction of the link break. In this approach, we have used three threshold received signal strengths. They are threshold received signal strengths $P_{threehold}$, $P_{critical}$ and P_{decode} respectively. At $P_{threehold}$, the node enters into link prediction process. At $P_{critical}$, the node enters into critical state, warns the upstream node about link break and forms alternate path prior to link break. The P_{decode} is minimum power allowed for the destination node to decode the packet.

In this design, the received signal strength information obtained and calculated at the physical layer and then, is passed to the MAC layer for data transmission. The optimum transmit power is computed using equation (5.3). This P_{opt} is stored at each node in the optimum power table against the destination. In order to get the optimum transmit power in the cross layer design, the header fields of packets RTS, CTS, DATA and ACK are modified to incorporate the transmit power level of the respective packets.

Thus, when a node receives such packet, it gets the transmission power level P_t, the received power P_r is accessed from the physical layer and the calculated transmit power is pass to the MAC layer. This clearly indicates interaction between physical and MAC layers.

The node sending RTS inserts transmit power as an extra field in it so that the receiving node can tune to this power while sending its CTS packet. Subsequently by using the optimum transmit power level, the DATA packets from sender and ACK packet from receiver can also be transmitted.

5.1.2 Link availability

The link availability time can be estimated based on received signal strengths of packets from physical layer and the prediction of link break warns the sources and it can rediscover a new path before the path breaks [96].

The received signal strength in cross layer design is accessed at physical layer and can be used by upper layers. The measured value of received signal strength is transferred to upper layer alongwith the signal. This is used in calculations at common places and further passed to the routing layer alongwith routing control packets. This value is stored in the routing and neighbor tables and used in some of the decision making process related to selection of links forming the path. As an interlayer interaction parameter, the received signal strength, which is accessed at physical layer, is being used by upper layers. The calculation is accomplished by estimating the time at which received signal strength of the data packets will fall below a threshold power. The received power level below the decode power indicates that the two nodes are moving away from each other's radio transmission range and leading to link break.

In this approach, three consecutive measurements of signal strength of packets received from the predecessor node are used to predict the link failure using the Newton divided difference interpolation method. The Newton interpolation polynomial has the following generalized expression.

$$f(x) = f(x_0) + (x - x_0)f(x_0, x_1) + \cdots + (\prod_{i=0}^{n-1}(x - x_i))f(x_0, x_1, \ldots, x_n).$$

The received signal strengths of the three latest data packets and their time of occurrence are maintained by each receiver for each transmitter from which it is receiving. Using three received data packets' signal power strengths as $P_1,\ P_2,\ P_3$ and the time when packets arrived as $t_1,\ t_2,\ t_3$ respectively and P_p instants as the decode signal strength (P_{decode}) at the time t_p, one can determine t_p using equation (5.6). Chapter 3 can be referred for the calculation of the value of t_p. We assume that at the predicted time t_p, when received power level reduces to or less than decode power, the link will break. The expected signal strength of the packets received can be computed as below, where Δ and Δ^2 are first and second divided differences respectively.

$$P_p = P_1 + (t_p - t_1)\Delta + (t_p - t_1)(t_p - t_2)\Delta^2. \tag{5.5}$$

$$P_p = P_1 + \frac{(t_p - t_1)(P_2 - P_1)}{(t_2 - t_1)} + (t_p - t_1)(t_p - t_2)\,(\frac{(P_3 - P_2)}{(t_3 - t_2)} - \frac{(P_2 - P_1)}{(t_2 - t_1)})/(t_3 - t_1). \tag{5.6}$$

At time t_s, the node enters into critical state and node should find alternate route. A link failure warning is sent towards the upstream nodes and sources, whose flows are using this link. Source nodes can invoke the route discovery mechanism to setup restoration paths. The threshold power is the received power at the time t_s, sufficient for sending warning message to the upstream node and sources further to discover an alternate path by setting up new path.

5.1.3 Proposed protocol algorithm

The DPCPLP algorithm $P_t[L]$ is the set of power levels used for the transmission, where L is an integer varies from 1 to 7. The transmit power $P_t[L]$ is the maximum power level and the number of power levels in the set is 7.

A. Transmitter:

1. Let $P_t[L] = 2.818$,
2. Check the optimum power table at the transmitter node for the receiver node address and its stored optimum transmit power value P_{tt},
3. If node entry is available, then $P_t[L] = P_{tt}$ else $P_t[L] = 2.818$,
4. Add this power value in RTS header and send RTS with this power level $P_t[L]$,
5. Receive CTS packet, observe its received power P_r and extract transmit power. The node calculates optimum transmit power for DATA packet,
6. Update optimum power table,
7. Add the power level in the DATA packet header and send the DATA packet at optimum transmit power level,

8. Receive ACK,
9. End.

B. Receiver:

1. For each neighbour,
2. On receipt of a packet,
3. If (P_r > $P_{\text{threshold}}$) then Powercontrol ()
4. Else
5. {
6. Update record of (received power, time) for last three packets,
7. If (($P_1 > P_2$) and ($P_2 > P_3$)) then Prediction (),
8. Prediction ()
9. {
10. Estimate and update the t_p and update the t_s, when node enters into critical state, prior to link break
11. }
12. If (current time >=t_s)
13. {
14. Sent warning message to upstream node,
15. Sleep for fixed duration.
16. }
17. On receipt of repair message,
18. Set the route and link status as soon-to-be-broken,
19. }

20. Powercontrol ()
21. {
22. Receive RTS,
23. Observe the receive power, extract the transmit power and then calculate the optimum transmit power for the CTS packet. Update optimum transmit power table with power level $P_t[L]$,
24. Insert the optimum transmit power in the CTS header and send the CTS packet at the same power level,
25. Receive DATA packet,
26. Include the optimum power level in the ACK packet header and send the ACK packet at this transmit power level,
27. }
28. End.

1. At source:
2. {
3. New path discover message received,
4. Discover new path,
5. Redirect traffic through new path.
6. }

5.2 Simulation and Results

We simulated AODV routing protocol, AODV with link prediction (AODVLP) and dynamic power control protocol with link prediction (DPCPLP) using ns-2 [82]. In the simulations, we have varied three parameters – node velocity, network load (rate of generation of packets) and number of nodes in a given area. The detailed simulation parameters are mentioned in table 5.1. Numerous simulations were run with same parameters and average of observed values was taken to reduce the estimation error.

5.2.1 Simulation Parameters

Two-ray radio propagation model is used. We have used seven transmit power levels. Three parameters viz. node velocity, network load and node density were varied in the simulations. Network load is the rate of generation of packets in the network.

Table 5.1 Simulation parameters for DPCPLP

Traffic Pattern	Constant Bit Rate
Simulation Time	900 seconds
Total Connections	20, 25, 30, 35, 40, 45 and 50
Packet size	512 Bytes
Velocity	5, 10, 15, 20, 25 and 30 meters/second
Pause Time	10 seconds
Simulation Area	1500m by 300m
Total Nodes	25, 50, 75, 100 and 125

5.2.2 Performance Metrics

The performance of protocols have been evaluated in terms of average interruption time, overhead packets, energy consumption, throughput, packet delivery ratio and end-to-end delay as function of node mobility, packets generation rate and node density. Constant bit rate (CBR) sources are assumed in the simulation.

Average interruption time is the time during which ongoing communications are interrupted.

Routing overhead is the number of routing overhead packets that are generated in the network to transfer the data packets.

Energy consumed (in Joules) per 1 kilobyte data delivered is calculated as the total amount of transmitting and receiving energy consumption over all flows divided by the total data delivered by all the flows. The energy consumption of all the packets RTS, CTS, DATA and ACK are considered.

Throughput is the number of kilobytes transferred successfully by the sender to the receiver successfully.

Packet delivery ratio is the ratio of the data packets delivered to the destination to those generated by the CBR sources. The higher the value better is the performance.

Average end-to-end delay of data packets includes all possible delays caused by buffering during route discovery, queuing at interface queue, retransmission delays at MAC layer, propagation and transfer time.

5.2.3 Simulation Results and Analysis

The simulation results are obtained for AODV, AODVLP and DPCPLP. The velocity is varied in discrete steps as 5, 10, 15, 20, 25 and 30 meters/second for a fixed network size of 50 nodes and pause time of 10 seconds in figures 5.3 and 5.4. Figure 5.3 shows the comparison of the average interruption time in DPCPLP, AODVLP and AODV schemes. It shows that DPCPLP shows least average interruption time as compared to AODVLP and AODV. This is because DPCPLP uses smaller transmission range thus concurrent transmission of packets as well as uses backup path in case of route failures for restoration of path thus results in lowest interruption time as compared to AODVLP and AODV. However, AODV, AODVLP and DPCPLP give increasing average interruption time with increase in node velocity because faster mobility of nodes causes more route unavailability. Further, more route unavailability result in higher interruption time.

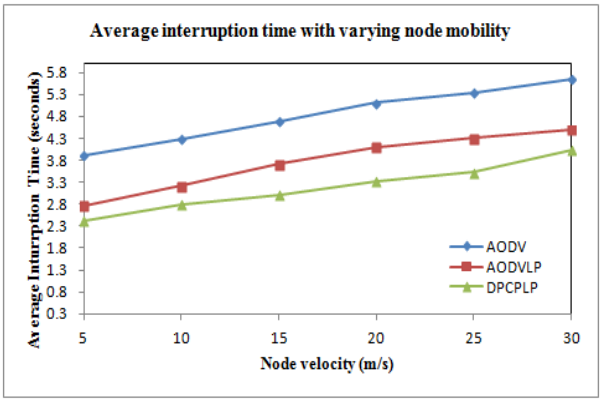

Figure 5.3 Average interruption time vs node velocity

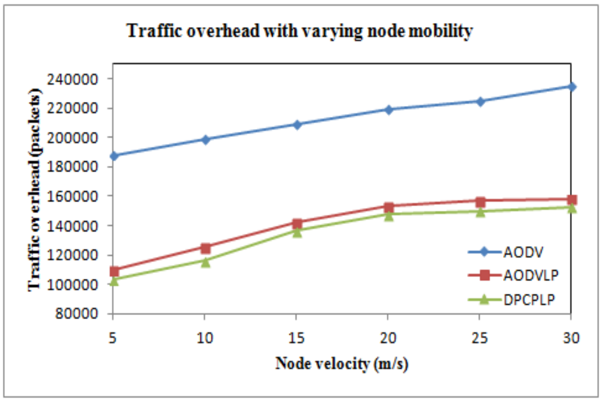

Figure 5.4 Routing overhead vs node velocity

Figure 5.4 shows that the overhead packets are least in DPCPLP as compared to AODVLP and AODV, because more packets are transferred concurrently due to smaller carrier sensing range in addition to availability of alternate routes in case of route failures caused due to higher node mobility. However, in DPCPLP, AODVLP and AODV schemes, the routing overhead packets increase with increase in node velocity. This happens because increase in node velocity increases more route unavailability for fast moving nodes. Therefore, overheads of new route discovery lead to increase in the routing overhead packets.

The packets generation rate is varied and other simulation variables are kept constant for a fixed network size of 50 nodes and pause time of 10 seconds and velocity as 5 meters/second in figures 5.5, 5.6, 5.7, 5.8 and 5.13. Figure 5.5 shows that in DPCPLP, the average interruption time is least as compared to AODVLP and AODV because of availability of path for increasing packets flow. The interruption time is least in DPCPLP as RTS, CTS, DATA and ACK packets are transmitted at lower power as well as availability of restoration paths in case of link failures. However, AODV, AODVLP and DPCPLP give increasing interruption time as packets generation rate increases. At low packet generation rate, less packets would be contending and at higher network loads, more packets would be contending for the transmission and thus, more interruption time. Therefore average interruption time increases with increase in packet generation rate.

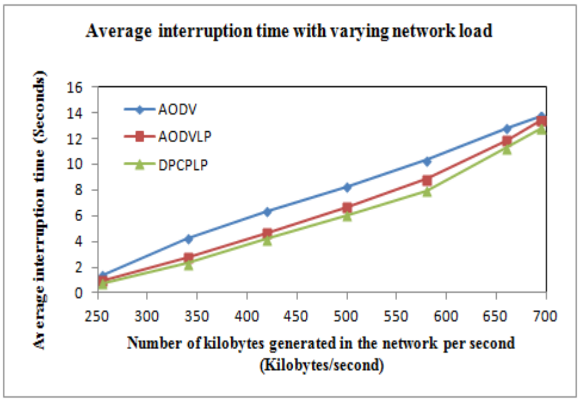

Figure 5.5 Average interruption time vs packet generation rate

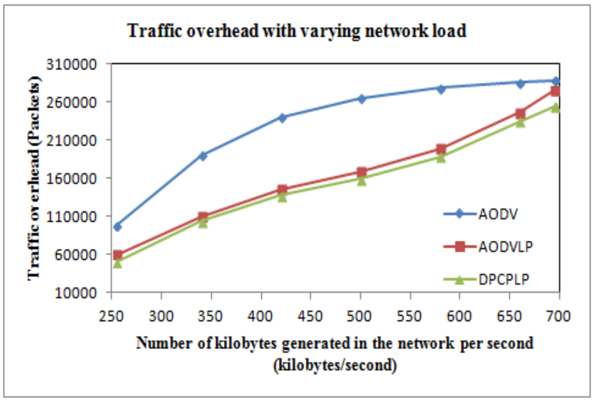

Figure 5.6 Routing overhead vs packet generation rate

In figure 5.6, The DPCPLP scheme generates least overhead routing packets as compared to AODVLP and AODV schemes due to concurrent transmission of the packets due to lower transmit power and prior route discovery before link failure, which avoids retransmission of the packets in the network. In AODV, AODVLP and DPCPLP, the routing overhead packets are increasing with increase in number of generated data packets because this increases contention and collisions. At very low packet generation rate, AODV, AODVLP and DPCPLP generate lower overhead packets. The result shows that by increasing the packet generation rate, the overhead packets also increases because more data packets are contending for the transmission channel thus more overhead packets are generated for retransmission of the packets.

Figure 5.7 shows the comparison of the throughput of AODV, AODVLP and DPCPLP. It shows that DPCPLP achieves highest throughput compared to AODVLP and AODV schemes. This is because DPCPLP uses smaller carrier sensing range compared to AODVLP and AODV, therefore large number of nodes can transmit concurrently. Results show that throughput is the higher in AODVLP as compared AODV. It happens because in DPCPLP and AODVLP, additionally alternative routes are discovered in advance before a link failure, and delivers a message through alternative route. However, DPCPLP gives increasing throughput as packet generation rate increases and saturates. The throughput remains constant after a particular point. As at low packet generation rate, less number of packets would be contending for the transmission and at higher network loads, due to reduction in power also reduces the number of deferring nodes, and thus, more data can be delivered per joule, therefore throughput increases linearly and saturates at higher packet generation rate.

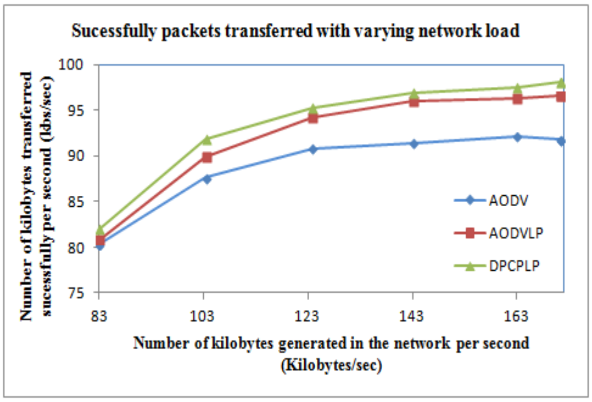

Figure 5.7 Throughput vs packet generation rate

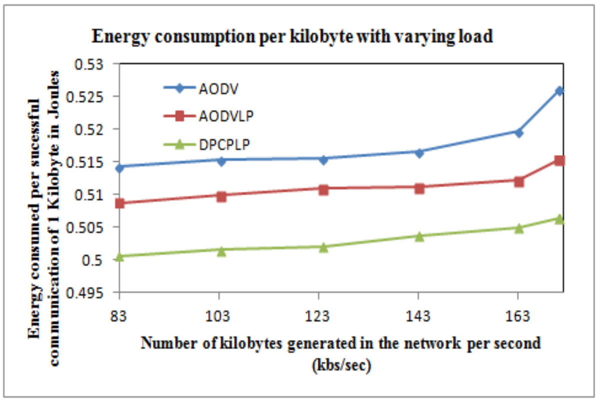

Figure 5.8 Average energy consumption (in Joule) per communication of 1Kbyte of data vs packet generation rate

Figure 5.8 shows variation of energy consumed per successful communication of 1 kilobyte of data with increase in packet generation rate. Results show that power consumption per successful communication of 1 kilobyte of data is lowest in DPCPLP as compared to AODVLP and AODV. DPCPLP is least power consuming as compared to other schemes as it uses lower power for communication of RTS, CTS, DATA and ACK packets and link successes are also observed and avoiding retransmissions of packets. However, DPCPLP, AODVLP and AODV give increasing average energy consumption as network load increases, since more packets are generated and contending in the network and thus these packets are send to the destinations therefore, more energy is consumed in successful communication of these packets.

The network size is varied and other simulation variables are kept constant with pause time as 10 seconds and velocity as 5 meters/second in figures 5.9, 5.10, 5.11 and 5.12. In figure 5.9 shows that the throughput per node is best in DPCPLP as compared to AODVLP and AODV. This happens because in DPCPLP scheme, concurrent transmission due to use of optimum transmit power, which is lesser as well as proactive route discovery in case route failures and thus more data is delivered. The throughput per node is decreasing in all the schemes with increase in number of nodes because this increases contention and collisions. At very low density, the AODV, AODVLP and DPCPLP give higher throughput because contention and collisions are less. At high density, all the three schemes give lesser throughput as contention and collisions are more due to more neighbouring nodes in the vicinity.

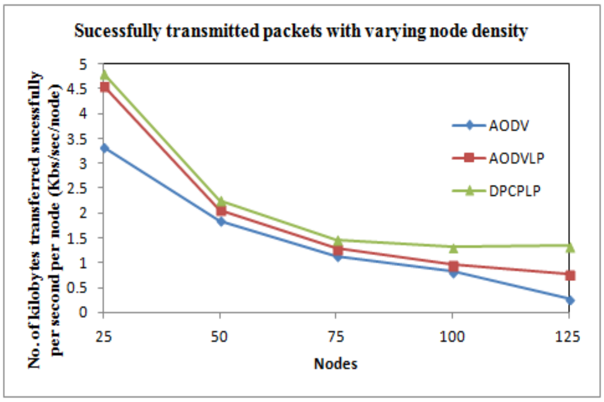

Figure 5.9 Throughput per node vs no. of nodes

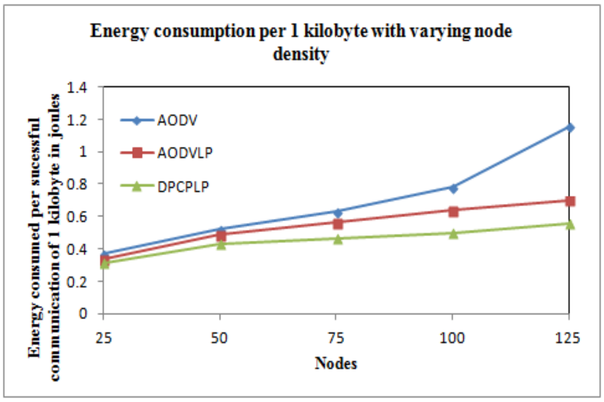

Figure 5.10 Energy consumption per communication of 1 kilobyte data vs no. of nodes

Figure 5.10 shows that protocol DPCPLP saves energy and therefore more packets can be transmitted in lesser power. The energy consumption increases in case of all the schemes as the node density increases, contention and collisions also increase. But the energy consumption of the DPCPLP is least among all the schemes throughout the density variation thereby making it better protocol.

Figure 5.11 shows variation of packet delivery ratio with increasing node density. Results show that packet delivery ratio is best DPCPLP as compared to AODVLP and AODV. It happens because in DPCPLP, concurrent transmission takes place due to spatial reuse of the channel resulting from lower transmit power of the packets, in addition to DPCPLP and AODVLP schemes discover alternative routes before the route failures, and more data is successfully delivered to the destination. However, DPCPLP, AODVLP and AODV give decreasing delivery ratio as node density increases, since it causes more contentions and collision due to more neighbouring nodes in the vicinity and therefore, decreases delivery ratio by retransmitting the packets more than once.

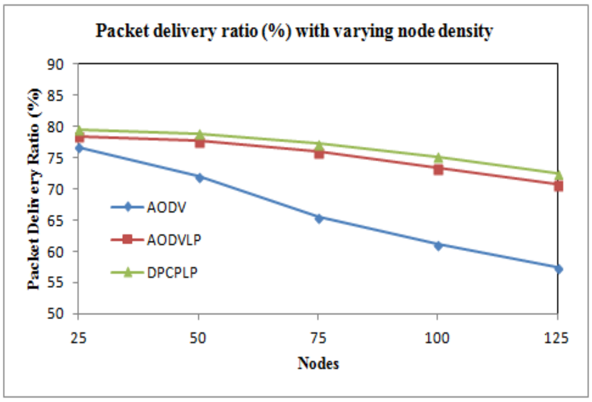

Figure 5.11 Delivery of packets vs no. of nodes

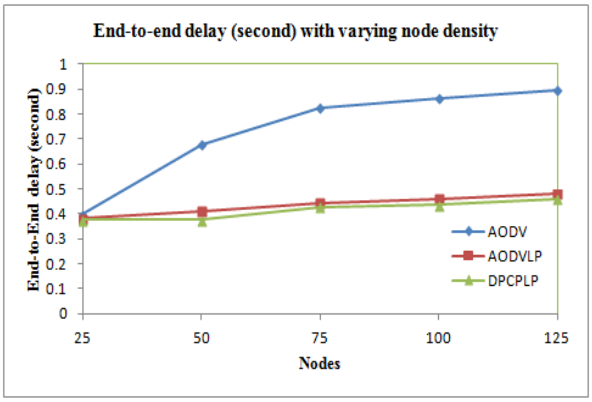

Figure 5.12 End-to-end delay vs no. of nodes

The end-to-end delay is an average of difference between the time a data packet is originated by an application and the time the data packet is received at its destination. Figure 5.12 shows lowest end-to-end delay in DPCPLP as compared to AODVLP and AODV because DPCPLP takes care of concurrent transmission of packets due to lower transmit power for RTS, CTS, DATA and ACK in addition to prior route discovery in case of route failures. The end-to-end delay is lower in AODVLP as compared to AODV due to prior route discovery in case of route failures. At low density, the delay is low in all schemes and it increases with increase in density because high node density increases contention and collisions thus result in retransmission of packets.

5.3 Summary and future work

In this chapter, we have proposed cross layer design to provide a combined solution for link availability management and power conservation (DPCPLP) in adhoc networks. This extension is the addition of power control at MAC layer that minimizes power consumption, thus yields longer battery life alongwith prediction function predicts link breaks and proactively repairs it before breaks at network layer, based on received signal power of the three consecutive received packets and threshold signal power strength. Using the MAC layer RTS, CTS, DATA and ACK packets exchange, the optimum transmit power can be dynamically estimated based on ongoing transmission and accordingly the sender and receiver can adjust its transmitting power in sending RTS, CTS, DATA and ACK packets at optimum power, which is lower than maximum transmit power to its conserve energy sources.

The performance of the proposed cross layer design for the dynamic power control protocol and link prediction (DPCPLP) performs well as compared to AODVLP and AODV, This results in better throughput, lower energy consumption thus longer battery life and better delivered network because of lowest overhead routing packets and average interruption time due to use of optimum (lower) transmit power and prior route repair processes. Therefore, it improves networks and nodes' lifetime and capacity to support Quality-of-Service.

The suitability of proposed method for real-time traffic needs to be further studied by testing it with smaller sized CBR packets at a higher packet rates. The performance can also be evaluated for other power control and routing algorithm and considering other parameters e. g. congestion control at transport layer. Further, other power optimization and prediction methods should be evaluated.

CHAPTER 6

Conclusion and Future Work

In this chapter, contributions, conclusions and directions for future work have been presented. Mobile adhoc networks have been a popular research topic in the last few years due to their many applications in the civil and military fields. The standard IEEE 802.11 and ordinary routing protocols are preferred for applications where the reliable and quick delivery of data is important. But in some applications, the requirement is of improved performance of the network to support mobility and hence incorporation of link prediction in routing is very important. The lifetime of a mobile node and hence energy conservation is also very important. They lead to increase in packet delivery ratio and the network lifetime so that the performance of the network does not degrade too soon.

The goal of the present work was to minimize packets drops by switching to alternate path even before links fail with the help of link prediction and to reduce energy consumption in an adhoc network while maximizing the network throughput. In this thesis, we have focused on link prediction, energy efficient MAC protocol and cross layer design for combining the power control and prediction of link availability in the mobile adhoc networks.

In this thesis, we have proposed link prediction algorithm alongwith AODV routing algorithm. This algorithm uses received signal strengths of packets for link prediction on identifying the possibility of link failure in near future. It sends route error message towards the source node before the link breaks so that source node can find an alternate path to transmit the data before failure. The link prediction in AODV has been simulated using NS-2 network simulator and the results show that performance of link prediction with AODV is better than plain AODV routing algorithm.

We also proposed dynamic power control wireless MAC protocol (DPCP) for energy conservation. It was simulated using NS-2 network simulator, and the results show that performance of DPCP is better than IEEE 802.11b std.

Finally, we proposed a cross layer design for power control and link prediction in mobile adhoc networks (DPCPLP) that provides a combined solution for power conservation as well as link availability. The received signal strength of the packets is used as cross layer interaction parameter. This combines the effect of optimum transmit power and received signal strength based link availability estimation with AODV routing protocol using cross layer approach. This method proposes to use optimum transmit power for transmitting the packets to a neighboring node to increase the battery life of adhoc nodes and received signal strength based link prediction to increase the availability of the links. The proposed scheme (DPCPLP) outperforms the AODVLP and AODV. Results show that the proposed protocols perform better than the already existing schemes (AODVLP and AODV) in terms of increase in throughput, packet delivery ratio and decrease in average interruption time, routing overheads, end-to-end-delay and energy consumption.

6.1 Contributions

The contributions of this thesis are in terms of link prediction, power control, and cross layer design to implement the power control and link prediction in mobile adhoc networks. Further by proposing modifications to the existing schemes network performance is predicted to be improved by reducing packets drop and conserving more energy while maintaining the maximum throughput. The contributions of the work reported in this thesis are listed as follows:

- Developed a new link prediction model based on newton divided difference method using received signal strength of the packets.
- Using link availability model with AODV routing algorithm, the performance enhancement has been predicted.
- Performance evaluation of link prediction model with AODV routing algorithm (AODVLP) was done. Further it was compared with original AODV routing algorithm.
- Developed dynamic power control protocol (DPCP).
- Performance evaluation of DPCP protocol and its comparison with IEEE 802.11b std. scheme was done.
- Developed cross layer design for power control and link availability in mobile adhoc networks using transmit power and received signal strength of the packets as cross layer interaction parameters.
- Performance evaluation of proposed cross layer design using power control and link availability model, and their comparison with AODVLP and AODV algorithms was also done.

6.2 Conclusions

Results were obtained after simulations conducted in NS-2 network simulator. After examining the results, the conclusions are as follows:

- The link prediction model with AODV routing algorithm (AODVLP) is better than the original AODV algorithm alone.
- Link prediction with AODV (AODVLP) does improve the QoS by reducing the end-to-end delay, restoring the links before route failures, reducing the average RTS collisions per node and by increasing delivery ratio.
- The dynamic power control protocol (DPCP) performs better than IEEE 802.11b std. in terms of reduced energy consumption and increased throughput.
- The cross layer design of power control and link availability in mobile adhoc networks (DPCPLP) performs better than its counterparts – AODV with (AODVLP) and without link prediction (AODV).
- The cross layer model for power control and link availability (DPCPLP) do improve QoS by reducing end-to-end delay, average interruption time, routing overheads, energy consumption, by increasing delivery ratio and throughput.

6.3 Future Work

The recommendations for the future work are as follows:

- Other methods can also be explored for link prediction model.
- We can also incorporate proposed model in other existing routing algorithms and compare them with DSR and LAR routing algorithm results.
- Performance of link prediction routing can be evaluated for real time traffic.
- Other power optimization protocol may be integrated to improve the performance of the network.
- The cross layer integration can also be included for other layers to further optimize the performance of the networks further.
- A lot of research can also be done in the other layers of the protocol stack. Therefore this study can be extended to design protocols with other schemes to achieve improved efficiency.

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