Chapter 5
Three-Layer Cross Architecture

In this chapter a three-layer cross design is analyzed that spans physical, MAC, and network layer for power savings. The Dynamic Source Routing (DSR) protocol with power control capability is proposed. The route reply control packets are piggyback with necessary information to allow the sender node to discover the required amount of transmitting power. Cross-layer design has of late turned into the new buildup in remote correspondence frameworks. Cross-layer conventions when utilized properly can accelerate expanded network lifetime and QoS. A cross layer design is especially essential for any network utilizing remote innovations, since the condition of the physical medium altogether fluctuate over the long run. Data trade between diverse layers can even advance the network throughput. A new straightforward cross-layer design named as Power-aware DSR (PA-DSR) is proposed for power protection dependent upon transmission power control. Power control capacity is given to the DSR. In PA-DSR, the RREP control indicators are utilized to piggyback the essential data to empower the transmitting hubs to uncover the obliged least measure of transmission power.

5.1 Introduction

As of late the widespread accessibility of wireless correspondence and hand-held gadgets has invigorated research on self-arranging networks that does not need any pre-established base. These ad-hoc networks, as they are usually called, comprise of self-sufficient node that work together keeping in mind the end goal to transport data. As a rule, these hubs gesture as close frameworks and switches in the meantime. The unavoidable challenging issues are power control, scheduling, and routing. These are identified with distinctive layers in the wireless convention stack. A few conventions have been designed autonomously without recognizing the associations between these layers. Thus, there is a need to give joint answer for all these issues with convention co-operations which can expedite expanded network effectiveness and QoS backing. For this, another idea called cross-layer design has been presented [86][87]. A cross-layer design is especially paramount for any network utilizing wireless advances, as the condition of the physical medium alter in the process of transmission. Data traffic between diverse layers can even advance the network throughput.

The primary centre is to advance and test an appropriated calculation for joint power control, planning, and tracking in wireless ad-hoc networks. The power controlled DSR convention basically focuses on reduction of the transmission power. Likewise the execution is measured by contrasting and the conventions in layered construction modeling where there are no connections between the layers wireless ad-hoc networks, which are broadly considered in needs solid coupling around the traditional layers of the construction modeling and these collaborations cannot be overlooked. In [88][89][90] it is pointed that adapting transmission rate dependent upon connection state data passed from physical to MAC layer, can enhance the execution of the IEEE 802.11 convention. An alternate connection, which expands network execution further, is coupling between network layer and MAC layer [90][91]. The communication link between the nodes in wireless environment has interference, so the bit rate of a node is a function of choice for the physical and MAC layer parameter. Next complication of wireless networks is that the network topology and channel condition keeps changing in time due to environmental factors and node mobility. The link transmission rate $\mu(t)$ is based on network topology state S(t) during time slot t and link control action $I(t)$ taken by the network during time slot *t* and can be expressed as

$$\mu(t) = C(I(t), S(t)) \tag{5.1}$$

All the uncontrollable parameters in the wireless networks are represented by $S(t)$. $I(t)$ is the control input decision taken on the $S(t)$ topology state. In this case, $I(t)$ would refer to the matrix of power values and bandwidth allocation decision over the data links. The network controller observes the network state topology for selecting $I(t)$, abiding the transmission control policy [92]. So as to advance a conveyed calculation together for these issues, it is needed to think about the tracking and MAC conventions plus power, control provided that power control is not acknowledged in any of these conventions, the issue of multi-client obstruction expands and offers ascent to lessening in the throughput of the network. Likewise, utilizing the settled power transmission levels for the information bundles decrease the life time of the electric cell. The CSMA/CA of the Wireless Local Area Network (WLAN) is mingled with the power control calculation. The trade of RPTS/APTS control indicators is utilized to piggyback the essential data to empower the transmitting hubs to uncover the obliged least measure of power that is required to transmit information bundles. In the power control system, it is connected at MAC layer so now information parcels could be transmitted with least decreased power [86][91].

5.1.1 Link-rate of Ad-hoc Network with Interference

The mobile nodes are equipped with transmitter and receivers having certain power values. The transmission rate function $C(P(t), S(t))$ can be given by the power vector $P(t)$ satisfying peak power constraints at every node and depends on the Signal-to-Interference and Noise Ratio (SINR) [93][94] that can be stated as

$$C(P(t), S(t)) = log(1 + SINR(P(t), S(t))) \tag{5.2}$$

SINR is given as

$$SINR(P(t), S(t)) = \frac{P(t)\alpha_{\mu}(S(t))}{N_0 + \sum P(t)\alpha_k(S(t))} \tag{5.3}$$

where N_0 denotes the background noise intensity of the transmission links and $\alpha_k(S(t))$ is the attenuation factor at the receiver of the signal power transmitted by the transmitter of link *k* when the topology state is S(t).

5.1.2 Routing and Network Layer Queuing

The data packet entering the network layer contains source node address, destination node address, and priority service class which can be treated as the commodity *C* of the data and *K* is the set of commodities. The amount of new commodity *C* data arriving exogenously to source node *i* during slot *t* is represented as $A_i^{(c)}(t)$ from the application layer to transport layer.

$U_i^{(c)}(t)$ is the current backlog of commodity *C* stored in the network layer queue. In a special case, if node *i* is the destination of the commodity *C* then $U_i^{(c)}(t) = 0$ for all time slot *t* then it exits from the network layer.

The network layer control algorithm takes decision of routing, scheduling, and resource allocation based on the current topology state and queue backlog information. The resource allocation decision I(t) determines the transmission rate $\mu_{ab}(t) = C_{ab}(I(t), S(t))$ over the link (a,b) over time slot *t*. The routing decision is $\mu_{ab}^{(c)}(t)$ offered to commodity *C* over link (a,b) during slot *t* has certain constraints.

$$\sum_{c \in k} \mu_{ab}^{(c)}(t) \leq \mu_{ab}(t) \tag{5.4}$$

$\mu_{ab}(t) = 0$ if (a, b) does not belong to L_c that is the set of all links that commodity c data is allowed to use.

The link constraint set L_c restrict *C* from using commodities outside this set. For constraint set, it may be restricted to single hop networks where only direct transmissions between nodes are allowed. An unconstrained set can contain all the links of the network and routing decisions can be taken dynamically where packets of the same commodity may traverse multiple paths. Unconstrained set allows multiple options but becomes complex and leads to network delays. The link set must be designed in advance to reduce delay and ensure predictable performance. Both unconstrained and constrained routing allow for a multiplicity of paths. In cases when it is desirable to restrict sessions to a single path i.e., to ensure in-order packet delivery, each set L_c can be specified as a directed tree with final node given by the destination node for commodity *C*. A different commodity *C* is associated with different source-destination pair that cross each other but do not merge the link set L_c is defined as the set of all links in the path for commodity *C*.

5.1.3 Flow Control and Transport Layer

The exogenous data $A_i^{(c)}(t)$ enter the transport layer and this data is stored in buffers before being accepted by the network layer. Assuming $R_i^{(c)}(t)$ is the amount of commodity that is allowed to enter network layer from transport layer. There is separate buffer space for each commodity at each node and define $L_i^{(c)}(t)$ as the backlog of commodity *C* bits in the transport layer buffer. The source node takes flow control decision by selecting

$$R_i^{(c)}(t) \leq L_i^{(c)}(t) + A_i^{(c)}(t) \quad for \;\; all \;\; t \tag{5.5}$$

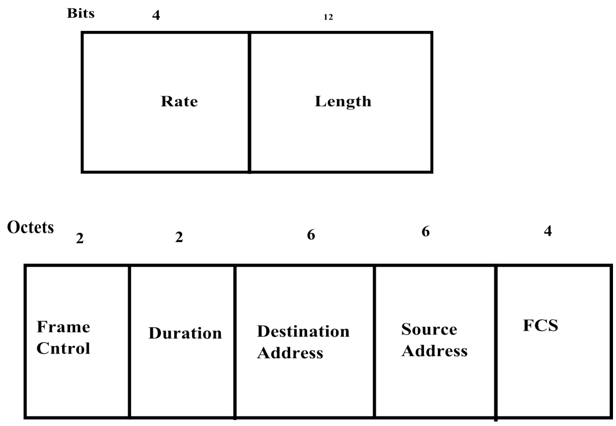
Some of the data must be dropped if the new exogenous arrivals are not admitted to the network layer and do not fit into the storage buffer. The buffer size is bounded as $L_i^{(c)}(t) \leq L_i^{max}$. The buffer for each commodity may be infinite or finite, with size $0 \leq L^{max} - i \leq \infty$

5.2 Congestion-awareness through Cross-Layer Interaction

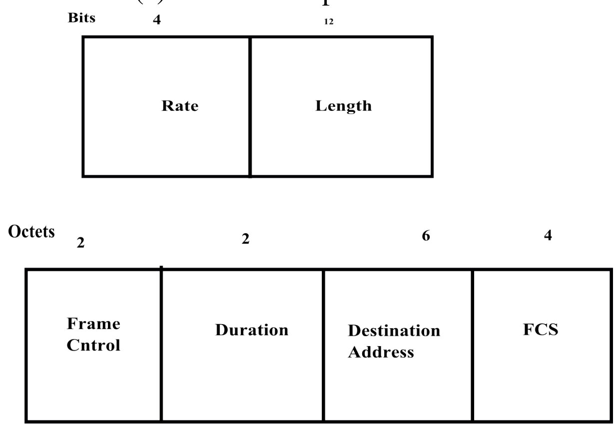
In order to get rid of energy wastage, it is always better to be well prepared about the congestion status in the network. Cross-layer energy can be conserved when congestion can be controlled. It involves two schemes: rate adaptation and congestion aware. Rate adaptation is done in the MAC layer based on channel estimation from physical layer and congestion information from the network layer. The congestion aware can be exploited from the congestion information in the network layer from MAC layer.

5.2.1 Channel Information for Rate Adaptation

The rate adaptation scheme is actualized with minor alteration to the IEEE 802.11 MAC convention. In this scheme, a source node sends RTS bundle before it transmits any information. The point when the end node appropriates this RTS, it assesses the indicator quality in place of SNR [95] of the transmission channel since indicator quality is a more reasonable parameter. The transmission power of every parcel is known and the receive power might be assessed by utilizing the channel model reenactment [96] At that point the signal strength is mapped to a transmission information rate dependent upon a proficient rate adaptation calculation [97]. This transmission rate data is held in CTS bundle and sent over to the source node. The source node will then send information because of current circumstances. Other neighbour hubs that hear the CTS will upgrade the data of the channel busy period in their network allocation vector (NAV) and hold their transmission until current transmission is finished. To evade the extra overhead to get rate data, the IEEE 802.11 RTS/CTS frame formats were modified. The definitive Duration field is changed to Rate (high 4 bits) and Length (low 12 bits) field.



(a) RTS control packets frames



(b) CTS control packets frames

Figure 5.1: RTS/CTS in Rate Adaptation

The RTS includes basic data rate and packet length in place of transmission duration. The receiver node selects an optimal data rate based on the signal strength of the received RTS, the new selected data rate and packet length is sent back to the sender in the CTS. The sender node will uses the data rate to transmit data packets. The neighbour nodes that hear the RTS/CTS calculate the duration from the data rate and packet length, and set their NAV. For the rate adaptation algorithm, simple threshold based technique is used. In this scheme, the rate is chosen by comparing the channel quality estimation against a series of thresholds related to the available M-QAM modulation schemes [97]. In the simulation, power-received indicator (Pr) represents the channel quality estimation. It is the ratio between the received signal strength and received threshold. The rate is given by $b_i = log_2(M_i)$, where Mi is the constellation size of M-QAM. The rate is set in the units of 500 kbit/s by adapting the IEEE 802.11 MAC standard. Accurate estimation of transmission rate usually reduces the probability of collision. Instead of using one instantaneous sample of the received signal strength of the current RTS packet [98] the signal strength is estimated by a simple moving average window the previous and current samples of RTS to smooth deep fading. This results in better channel usage efficiency and higher total throughput especially when the communicating nodes are moving.

5.2.2 Congestion Information for Rate Adaptation

The queue length is used as the congestion information for rate adaptation. When congestion occurs, MAC layer of the sender node prefer to select high data rate but the receiver side is prone to reduce the data rate to avoid congestion in the already congested queue. While the queue length Qs of the sender is greater than a preset Threshold, the sender rate Bs is increased by a factor α, $(0 < \alpha < 1)$; otherwise, it uses $default_{rate}$. On the other hand if the receiver is congested, the receiver rate ***Bq*** based on queue length ***Qr*** is decreased by a factor β,$(0 < \beta < 1)$. The same power-received indication ***Pr*** defined in the last section is also used as another rate selection metric at receiver to get rate ***Bss***.

The final receiver selection rate is calculated by summing ***Bq*** and ***Bss***, this is used by the transmitting node and receiving node for communication The support rates are all in the units of 500 kbit/s, which is set as $unit_{rate}$. So ***Bs*** and ***Br*** are all integers and the $select_{rate}$ is the final rate used in the RTS/CTS frame.

Sender End:

$$Bs = int[\frac{(1 + \alpha * Qs/Threshold) * default_{rate}}{unit_{rate}}] \tag{5.6}$$

$$select_{rate} = Bs * unit_{rate} \tag{5.7}$$

Receiver End:

$$Bq = Bs * (1 - \beta * Qr/Threshold) \tag{5.8}$$

$$Bss = log_e(Pr) - 1 \tag{5.9}$$

$$Br = int[Bq + Bss] \tag{5.10}$$

$$select_{rate} = Br * unit_{rate} \tag{5.11}$$

Qs is the queue length at the sender and Qr is the queue at the receiver

The less congested route as opposed to the briefest route is less averse to be utilized within this scheme. It expands the decency of the generally unarranged system, which is particularly imperative to the vigor compelled sensor systems. It additionally lessens the sum end-to-end delay of a bundle, which incorporates transmission delay, handling delay, and queuing delay. The point when a bundle goes through the longer yet less congested tracks, the transmission delay might somewhat build, however, it decreases more holding up time because of shorter queues of middle nodes. Suppressing RREQ forwarding at busy nodes has two trade-offs. It may unable to discover the route to destination when a route actually exists but through the busy area. Forcing the route to avoid the congested area may cause a node to find a longer route than the shortest one. This leads to additional traffic overhead to other areas of the network.

5.2.3 Congestion Information in Network Layer

To utilize the congestion information in the modified DSR, the Routing discovery mechanism was modified. When an intermediate node receives a Route Request packet that is not directed to it, then it checks the congestion parameters. When the congestion parameters are higher than threshold values, this will indicate high level congestion around the node. Forwarding RREQ packet to other nodes will aggravate the congestion in two factors. Sending the RREQ packet will increase the usage of the medium around the congested area and it will lead to a new route across the busy area that will result to additional transmission burden. The busy nodes on this congested path will silently drop the RREQ packet instead of handling and forwarding So, the discovered routes bypass the congestive nodes. The less congested routes rather than the shortest routes are more likely to be used in this scheme. The fairness of the network is increased when less congested routes are used that stands to be very important for the energy constraints nodes in the ad-hoc networks. Queuing delay, processing delay, and transmission delay that constitutes the end-to-end delay will be reduced. When a packet is sent via a longer yet lesser jamming route, there will be slight hike in the transmission delay but it will have lesser waiting time as a result of shorter queue in the intermediate nodes. The total delay is reduced using the congestion aware scheme.

5.3 Proposed Power-aware DSR Algorithm

Power aware DSR (PA-DSR) is designed by altering the existing DSR convention. DSR is a straightforward and effective routing convention outlined particularly for utilization in multi-bounce remote impromptu systems of versatile hubs. It permits the system to be totally self-ordering and self-configuring, without the need for any existing system framework or organization. The operation of DSR is dependent upon source routing, with every bundle to be steered convey in its header the complete grouping of bounces through which the parcel past. The critical playing point of source routing is that the middle hubs do not have to administer cutting-edge routing data for sending bundles, since the routing data has been reserved in the parcels for their destiny utilization. Not at all like different conventions, DSR has required no occasional bundles of any sort at any layer inside the system. All parts of the convention work actually on-interest and need intermittent action permit the amount of overhead parcels brought about by DSR to scale immediately to just that required to respond to changes in the presently utilizing tracks. Thus, DSR has extremely low overhead and has the ability to respond quite rapidly to changes in the system. The progressions are required in the track disclosure stage of DSR calculation. The RREP control packet is added up with the transmission power while sending over the route. Upon getting the RREP control packet, the source node measures the gained power of the RREP bundle and gathers the transmitted power of the RREP bundle that is piggybacked in the same bundle. At that point the source hub computes the path loss of the RREP bundle and ascertains its obliged least transmission power utilizing the least power needed for the recipient to catch the indicator. The recipient limit in addition to the way misfortune gives the ideal power needed for transmission at MAC layer.

5.3.1 Cross-Layer Design for Power-Controlled Routing

Cross layering is by and large proposed as an approach to let conventions communicate past what permitted by standard interfaces. In the present DSR convention, there is no data in regards to the power parameters [99][100]. To incorporate this in the proposed algorithm there is need for cross layer interaction between network, MAC and physical layer. The data imparted around these layers are: location of the node, power levels, distance between the hubs and noise levels. Imparting these parameters dependent upon the demands around the layers fulfill the employment of the cross layer outline work. At the physical layer, the accepted power of the RREP bundle is measured and is gathered. Likewise, different parameters like transmission power, radio wire additions are available at the physical layer. To execute the power controlling and tracking, these parameters are to be imparted around physical, MAC, and network layers. The accompanying figure shows this data. The channel estimation is performed in the physical layer that gives the Signal-to-Noise Ratio of the link. A sender node then selects the transmission rate R_i based on the estimated SINR that affects the packet delay D_i of the link layer. The routing decisions at the network layer are based on the packet delay associated with each link. The routing decisions will impact the delay, transmission rate, and SINR on each link.

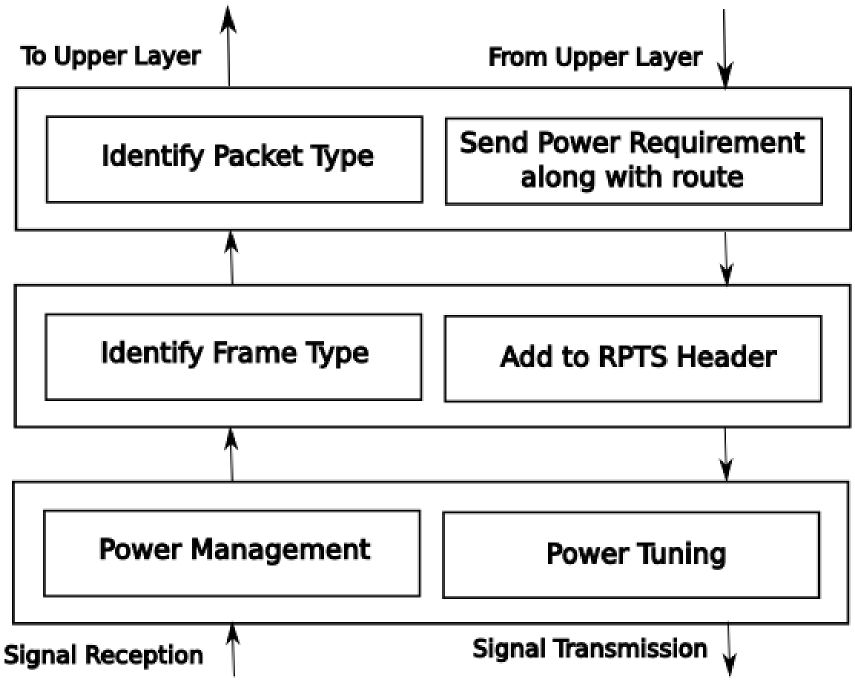


Figure 5.2: Cross-Layer Power-aware DSR

5.3.2 The Algorithm

1. The progressions are required in the track finding stage of DSR calculation. The RREP control packet is send to the specific source node with the transmission power in its header plus the route.

2. Upon appropriating the RREP control packet.
   (i) If the node is expected source then

(a) The Received power in the RREP packet is determined.

(b) The power at which the packet is transmitted is piggybacked in the same bundle.

(c) Then the node computes the path loss of the packet through the equation given below:

$$path_{loss} = Tx_{power} - Rx_{power} \tag{5.12}$$

(d) Later the node computes its obliged least transmission power utilizing the collector edge. The beneficiary edge $Recvr_{Thr}$ plus the $path_{misfortune}$ gives the ideal power needed for transmission at MAC layer.

$$MinTx_{power} = path_{misfortune} + Recvr_{Thr}. \tag{5.13}$$

(e) The Min Tx_{power} is computed at the routing layer is sent to the MAC layer, where the node sends out RPTS/APTS and information packet to the terminus with this decreased Tx_{power}.

(ii) If the node is transitional node then

(a) Performs all the estimations same as the source hub and transfers this RREP packet to the expected source through some middle of the road hubs.

(b) As the RREP is steered over along the opposite way, the nodes along the way will just setup forward track sections in their track table additionally constrained to enter the obliged power for transmission in the track.

5.3.3 Routing Metrics

A routing metric is assigned on every link, which shows the suitability of the link to be taken in the route selection. The worth of the routing metric is set from the knowledge provided by the MAC layer. The routing algorithmic program then computes the shortest path during which every link is weighed by its routing metric. Depending on the knowledge that is passed from the MAC layer, the routing algorithms may exhibit varied properties, such as bandwidth aware, interference aware, and congestion aware.

1. **Bandwidth Awareness**: The routing metric of a link *i,j* is defined as $\frac{1}{R_{i,j}}$. The total of the routing metrics along the chosen route is proportional to the overall time for a packet to

traverse the route, assumptive there is no queuing delay or packet retransmission. Since a link with high information measure incorporates a smaller weight, more routes will be assigned to utilize the link.

2. **Interference Awareness**: The delay $D_{i,j}$ in the MAC layer is the time interval between sending of RTS and receiving of data packet. In the regions where there is interference, MAC delay is high because of contention of the channel. The new routes should abandon from using the link.

3. **Congestion Awareness**: The queuing delay Q_i in the sender node is used as determine congestion in the node. The routing algorithm exhibits load balancing behaviour. Nodes with a large number of packets in the buffer are avoided. The congestion information at a node is determined by two congestion aware parameters [101]. One of the metric is average MAC layer utilization and other is instantaneous queue length at the network layer.

   - MAC layer utilization is set to 0, when the medium around a node is ready to transmit.
   - MAC layer utilization is set to 1, when a node is detecting physical carrier or deferring due to virtual carrier sensing.

   As the MAC layer utilization is either 1 (use) or 0 (idle), the value is averaged to indicate the used percentage of the wireless medium around the node. The value per 0.01 second is sampled to get MAC layer utilization over 100 latest samples. The other metric is instantaneous queue length at the network layer. If a node has many packets in the queue, it will cause long packet latency or even packet drop.

5.4 Implementation

The aim is to show the benefits of cross-layer interaction in low mobility scenario where routing metric is modified for only route discovery but not route maintenance. To carry out a path discovery, the source node broadcasts RREQ packet that is flooded through the network that is replied by RREP packet from either the destination node or intermediate nodes having route to the destination. The original description of DSR supports unidirectional routes [102]. The 802.11 MAC protocol, however, assumes that links are bidirectional. The authors in [103] give a description of modified DSR implementation where only bidirectional routes are discovered. RREP packets are sent back using the reverse route of the RREQ packets. If the route taken by the RREQ packet contains unidirectional links, then the RREP will not reach back to the source. When the RREP packets are received at the source, the shortest path route is selected.

Channel estimation must be accomplished by the RREQ packets. Whenever a node receives a RREQ packet, the SNR is determined and then appended to the packet. At the destination node, the received SNR along the path of all routes is known. RREP packets are then sent with the current time as the time stamp. The RREP packets propagate along the reverse paths with rate adaptation at each hop. When the source node receives all the RREP packets, the MAC delay for the reverse paths are computed by subtracting the packet time stamp from the current time. The route with the minimal MAC delay is selected.

In NS 2.34, for implementing the cross-layer inside the TCL script enable the energy model and set the initial energy values as

```
set val(rp)              DSR
set val(energymodel)     EnergyModel
set val(initialenergy)   100
```

Inside the node configuration, set the energy model, initial energy value, power spent in receiving, transmitting, idle mode, and sleep mode

```
ns_node_config    -energyModel      $val
                  -initialEnergy    $val
                  -rxPower          $val
                  -txPower          $val
                  -idlePower        $val
                  -sleepPower       $val
```

For cross-layer interaction, to access the physical layer from the routing layer. Inside the dsr.h file the mobilenode.h file is included as
include<mobilenode.h>
A physical object is declared as Phy `*netif_` within the DSR class. In the DSR.cc file the following codes are included

```
int DSR::command(int argc, const char *, const * argv) {
 elseif(strcmp(argv [1], access-phy )== 0) {
```

```
  netif_=(Phy *)TclObject::lookup(argv[2]);
  if(netif_==0) {
fprintf(stderr, Agent:%s-lookup-%s failed\n ,argv[1],argv[2]);
returnTCL_ERROR;}
else {
  double posx,posy,posz;
((MobileNode*)netif_->node())->getLoc(&posx,&posy,&posz);
printf( node_location:%f%f%f\n ,posx,posy,posz);
return TCL_OK; }}}}
```

In the `mac_802.11.h` an object is created as Myrouting *myrt;
And in `mac_802.11.cc` the following code is included as

```
void Mac 802_11::set Myroutinglayer(Myrouting *rt)
{ myrt=rt;}
```

5.4.1 Simulation Details

NS 2.34 [104][106] was used for simulation developed by the Monarch Project [105][107] having wireless extensions. The aim is to show the effect of rate adaptation and use of the routing metrics. Two scenarios are considered for the experiment, stationary and pedestrian. The pause time for both scenarios was set at 1.0 seconds. The application traffic pattern consists of 20 CBR sources running on UDP that start at staggered times. For each speed, ten different mobility scenarios are generated. The maximum speed of each node is 1.0 meter/sec for the pedestrian scenario. 10 different mobility scenarios were generated for each speed and same communication channel was considered for all simulations. 20 CBR source destination pairs are generated randomly.

The load was varied by changing the packet size, number of flows and packet rate of the CBR traffic. In this simulation, the packet rate was changed from 10 to 60 packets/sec at a step of 10 packets/sec. These 6 offered load regimes were combined with 20 mobility scenarios as input files to the network simulator. Altogether 120 numbers of simulations was done, in each scenario, the traffic of five randomly picked flows is logged for performance analysis. The same five flows are logged in each scenario. There are ten mobility scenarios for each node.

The performance metrics are obtained by averaging over the monitored flows in all scenarios. [108][109][110].

Three performance metrics were used to evaluate the routing algorithm

1. **Packet delivery ratio:** The fraction of generated packets that are received at the destination node.
2. **Delay:** The average delay a packet takes to travel from the source to the destination node.
3. **Throughput:** The average bit rate at the destination node.

Three types of routing methods were used for simulation.

- **RA-IADSR**: Interference aware routing metric is considered in DSR for route discovery and rate adaptations in the MAC and physical layer.
- **RA-DSR**: Original DSR is used for route discovery and rate adaptation is used at the MAC and Physical layer.
- **DSR**: Original DSR is used for route discovery and no rate adaptation is used at the MAC and Physical layer.

The original DSR can be compared with RA-DSR method to show the impact of rate adaptation and RA-DSR can be compared with RA-IADSR to estimate the performance enrichment of the routing parameters.

5.4.2 Results and Discussions

Stationary scenario: When the load increases the average throughput increases. For original DSR, congestion begins to start at packet rate of 40 packets/sec and the throughput slides down when packet rate is raised. In the case of RA-IADSR and RA-DSR the network capacity is higher and no congestion is seen at higher packet rates. These schemes shows 40% throughput increased than original DSR. The RA-IADSR is slightly better than RA-DSR when compared throughput wise. The packet delay of RA-IADSR is 80% of that of the RA-DSR and 50% of that of the DSR. The RA-DSR and RA-IADSR have the same throughput performance; RA-IADSR is superior by smaller packet delays. The packet delay of each routing algorithm increases along with the offered load. The packet delivery ratio of the routing algorithms decreases with increase in the offered load. The RA-IADSR scheme has marginally better delivery ratio than the RA-DSR scheme, which in turn has a higher packet delivery ratio compared to the DSR scheme by more than 40%. For the DSR scheme, the packet delivery ratio is slightly over 0.4 at a light offered load of 10 packets/s. For the RA-DSR and the RA-IADSR schemes, the corresponding packet delivery ratio is slightly more than 0.6. In this regime, packet loss is neither due to mobility nor congestion, but is due to the wireless transmission impairments of Rayleigh fading. In slow fading environments, the deep fades span over duration of several consecutive data packets. The packets generated by the source will be queued up and dropped if the node buffer is full.

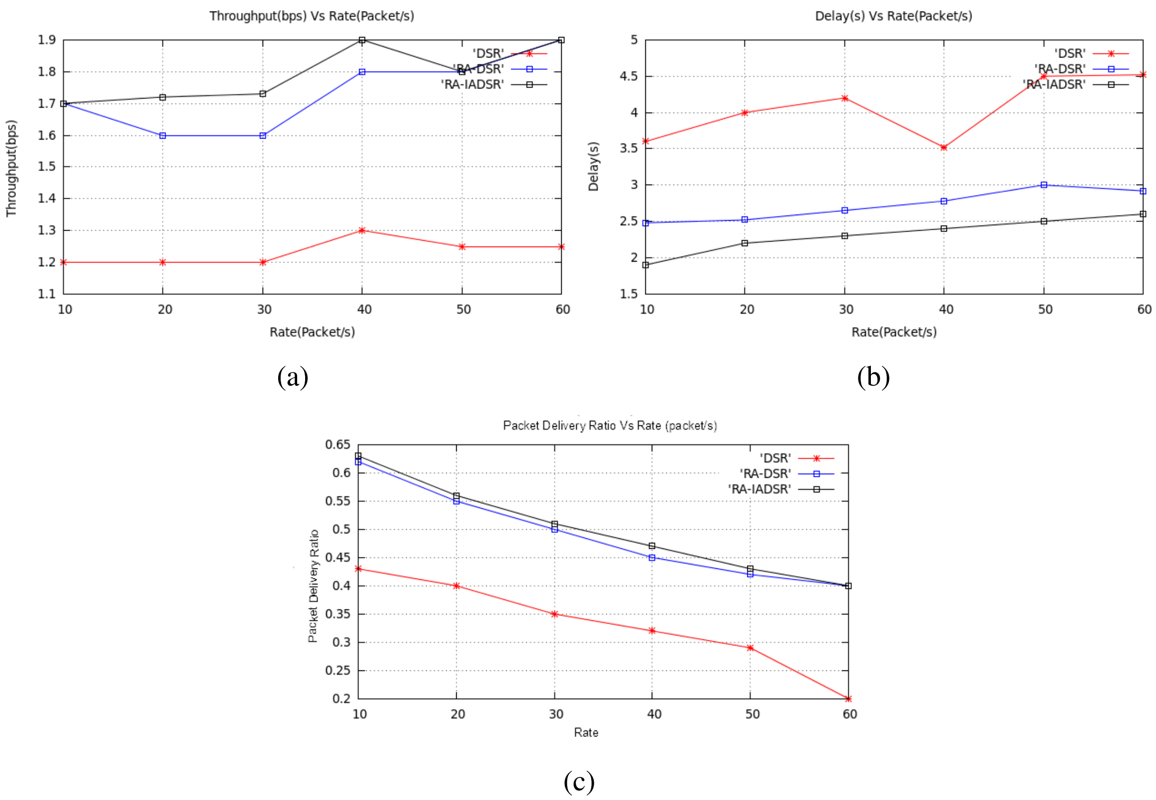
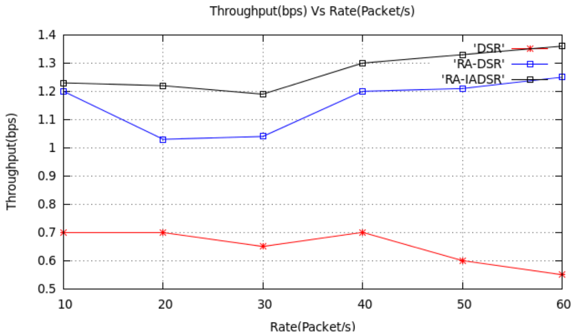
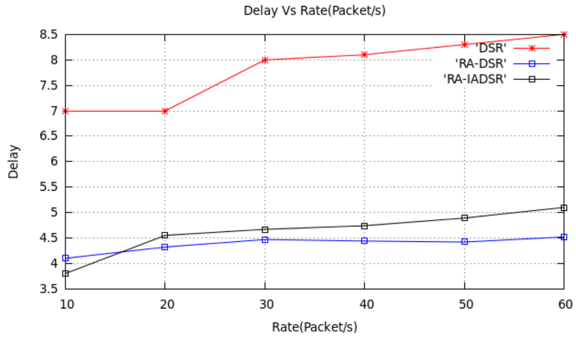


Figure 5.3: Stationary Scenario Case

Pedestrian scenario: Throughput is reduced when there in node mobility. However, there are differences in the performance between the RA-IADSR, RA-DSR schemes, and the DSR scheme. RA-IADSR, RA-DSR schemes have higher throughput than the DSR scheme by 80%



(a)



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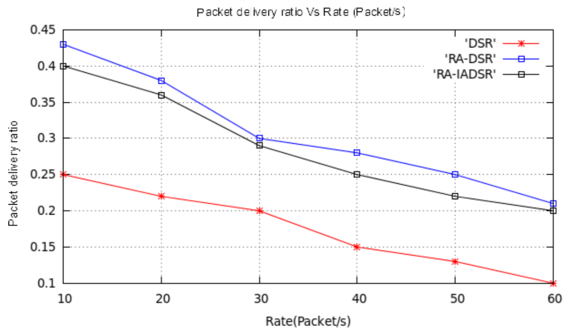

(c)

Figure 5.4: Pedestrian Scenario Case

to 90%. Mobility introduces faster variations in link capacity. A rate adaptation scheme could better exploit the dynamics of link capacity in high mobility scenarios. It can be seen that the RA-IADSR scheme consistently outperforms the RA-DSR scheme in throughput. This indicates the use of routing metrics leads to routes that are more robust to mobility. Compared with the stationary scenario the delays of all routing schemes are increased by more than 50%. This could be attributed to the occurrence of link failure due to mobility. It is seen that RA-IADSR scheme exhibits a higher delay than the RA-DSR scheme. The phenomenon that a scheme has a higher throughput and a higher packet delay could be explained as follows. Since the RA-IADSR scheme is more robust to mobility, routes with more hops are more stable in the RA-IADSR scheme and a large fraction of packets pass through these routes. The RA-DSR scheme is less robust to mobility. The most received packets of the RA-DSR scheme are routed through shorter hop routes. This explains the smaller overall delay in packet delivery. The delay performance in this case is misleading.

The higher delay of the RA-IADSR scheme is due to the robustness of the algorithm in mobility. In the pedestrian scenario, the packet delivery ratio is much smaller than the stationary scenario since mobility contributes to route failures and packet loss. Nevertheless, the packet delivery ratio of the RA-DSR and the IARA schemes is 90% higher than the DSR scheme. Rate adaptation and routing metric impact the performance of wireless routing protocols.

5.5 Conclusion

Through the use of cross-layer interaction between the MAC and physical layer the performance of the routing protocol can be improved. In this chapter a new design concept is incorporated in the routing protocols for MANETs. The concept is materialized by adding rate adaptation scheme to the IEEE 802.11 MAC protocol and routing metrics to the DSR protocol. By adapting rate adaptation of the links during route discovery, significant performance improvement is seen. There is moderate reduction in packet delay when rate adaptation is used. So cross-layer interactions are perceptible only in low mobility scenarios.

The benefit of the routing metric is more modest and moderate reduction in packet delay is obtained compared with the rate adaptation scheme. In this work, the routing metric is used only in route discovery. Thus, the benefit of cross-layer interactions is perceptible only in low mobility scenarios.