Routing and Load Balancing in Ad Hoc Networks

This chapter is devoted to routing and load balancing problems in MANET. To address the problems of route discovery and frequent topological changes, a rating based mechanism is developed. In this mechanism, each path is associated with its own rating. To increase Packet Delivery Fraction (PDF), host disjoint paths are selected by the respective MA. Rest of the chapter is organized as follows:

- Section 6.1 deals with the issues in MANET
- Section 6.2 presents routing and load balancing
- Section 6.3 deals with analysis of developed algorithm
- Section 6.4 gives implementation
- Section 6.5 presents results and discussion.
- Section 6.6 summarizes this chapter

6.1 Issues

MANET is a collection of wireless mobile hosts forming a temporary network without the aid of any centralized control or standard support services regularly available in wide-area networks. In MANET, it is necessary for a mobile host to seek the aid of others so that it forwards the packets to their destination. Critical issues in the design of MANET are the development of efficient routing protocols that can transfer the packets in
the presence of malicious hosts, continuous topological changes, higher PDF, etc.

6.2 Routing and Load Balancing

The communication in MANET consists of two phases- route discovery and data transmission. Keeping in view of the above defined challenging issues, we have designed an algorithm called RLBMA. RLBMA has two steps-routing with path maintenance and load balancing. In RLBMA, at any particular interval of time, two communication end hosts make use of set of diverse host disjoint paths that are deemed valid at that time. These sets of paths are called Active Path Sets (APS). With a set of host disjoint routes in hand; source host transmits the data along these paths to achieve higher PDF.

6.2.1 Assumptions

Each disjoint path chosen is associated with two types of ratings- a short term and a long term. These rating are defined by two parameters namely- availability and stability. The short term rating \(r_s\) is decreased by a constant \(\alpha\) each time a failed transmission is reported, and it is increased by a constant \(\beta\) for each successful reception. Similarly the long-term rating \(r_l\) also decrease or increase according to failed transmission or successful transmission. If \(r_s\) or \(r_l\), or both drop below a threshold value, \(r_{s\text{th}}\) and \(r_{l\text{th}}\) respectively, the corresponding path is discarded. For each path we have defined two parameters- \(a_i(t)\), \(s_i(t)\) named as availability and stability. Each parameter \(a_i(t)\) and \(s_i(t)\) is a \(1 \times m\) vector denoting the path availability and stability for all the paths. Each path is also assigned a cost parameter \(\lambda_i\) (say), which is a measure of number of hops traveled and bandwidth lost due to presence of selfish hosts from source to destination. This parameter gives a simple, yet effective control for selection of best path from the
available ones. In RLBMA, routing information on different paths is forwarded through messages to destination. Destination host selects the path with an appropriate cost. By weighing total cost of the path, congested paths are avoided. In order to keep up with frequent topology change, RLBMA provides quick response to link failure by patching up the broken routes in use. Each host sends a hello message to its neighbor to check the status of all its neighbors to update its topology. Hence route information stored at the destination host is used to select alternate paths whenever possible.

6.2.2 Algorithm

The RLBMA algorithm {Figure 6.1} is a two steps mechanism:

- Route discovery with path maintenance
- Load Balancing

Each path is associated with a rating and as the source transmits the messages across the APS, it updates the rating of the utilized paths based upon the feedback provided by the destination. According to rating of the paths, source transmits the data across less congested paths and achieves the goal of load balancing. Following agents are chosen in RLBMA:

- Route Discovery Agent
- Topology Update Agent
- Cost Computation Agent

The corresponding policies selected are:

- Route discovery policy
- Topology update policy
- Cost computation policy
Step 1: Route Discovery and Path maintenance

1. Let \( n \) is the number of paths available form source \( S \) to destination \( D \).

2. Define \( r_s^i \) and \( r_l^i \), \( 1 \leq i \leq n \) where \( r_s^i = \{ s \rightarrow C \}_{n} \) and \( r_l^i = \{ l \rightarrow C \}_{n} \)

/* Call RDA to choose the available paths as follows */

3. Repeat the following steps for each available path

4. if (successful transmission from \( S \) to destination \( D \)), increase both the rating as follows-

\[
\begin{align*}
    r_s^i &= r_s^i (0) + \alpha \\
    r_l^i &= r_l^i (0) + \alpha \quad \text{where} \quad 0 \leq \alpha \leq r_s^{\text{max}}
\end{align*}
\]

Else

\[
\begin{align*}
    r_s^i &= r_s^i (0) - \beta \\
    r_l^i &= r_l^i (0) - \beta \quad \text{where} \quad 0 \leq \beta \leq r_s^{\text{max}}
\end{align*}
\]

5. Set the value of \( r_s^{th} \) and \( r_l^{th} \)

If \( (r_s^i < r_s^{th} \text{ or } r_l^i < r_l^{th}) \), Discard that path.

/* Call TUA to update the topology by the given equation as follows */

6. After a random time interval re-compute the values of \( r_s^{th} \) and \( r_l^{th} \) for \( i^{th} \) path as below-

\[
\begin{align*}
    r_s (i) &= \left\{ \begin{array}{ll}
        \max\{r_s (i-1) - \alpha, r_s^{th}\} & \text{max} \\
        \min\{r_s (i-1) + \beta, r_s^{\text{max}}\} & \text{min}
    \end{array} \right. \quad \text{.................................(6.1)}
\end{align*}
\]

7. After the \( i^{th} \) transmissions across a path that include \( s \) successfully received (thus acknowledged) pieces and \( l \) lost ones, then \( i = s + l \), with \( s, l \) as integers.
Figure 6.1: Pseudo Code for RLBMA Algorithm

From the above figure it is clear that careful selection of values of $\alpha$ and $\beta$ reduces the packet loss. Also $\alpha \neq 0$, but $\alpha > \beta$. The values of $\alpha$ and $\beta$ would be updated from the above equations after each transmission.

6.2.2.1 Analysis

We have computed the overhead generated separately for each step-route discovery and data transmission during load balancing. We have chosen multi paths for various phases starting from source to destination.

We have assumed that there are $N$ hosts in the network. Mobile hosts are distributed with host density $\delta$ inside a region of radius $R$. Then $N$ can be expressed as: $N = \pi R^2 \delta$. Each link between the hosts has a link breakage
rate $\mu$, i.e., a link has average life time of $\frac{1}{\mu}$ sec. Let the average route length in terms of number of hops for multiple routes is $L_m$. It is assumed that $L_c$ is the average length of route from source $S$ to destination $D$ and $N'$ is the number of path for each source destination pair, and the number of active connection per host are $A'$. The source broadcast a route request packet (RRQ) to destination $D$. The first host receiving the RRQ that has a valid route for destination $D$ initiates a route reply packet (RRP) back to host $S$ containing a list of hosts along the path from $S$ to $D$. If data link layer of the host detect a transmission error, then host $D$ creates a route error packet (ERR) and transmit it to source. We have assumed that size of RRQ, RRP, ERR are denoted by $s_{rq}, s_{rp}, s_e$. A route discovery takes $T$ seconds to find the route from source to destination.

A perfect load balancing mechanism distributes traffic among hosts in the network. So packets have lower average end to end delay. Let $L_m, \lambda_m, \eta$ are respectively the average length of the route, host-to-host traffic rate, and the processing rate. Since the number of hosts is $\pi R^2 \delta$ in a particular region of radius $R$, so total number of possible connections within the network is $(\pi R^2 \delta - 1) \pi R^2 \delta$. With an average route length between the two hosts is $L_m$, the total traffic with in the network is $(\pi R^2 \delta - 1) \pi R^2 \delta L_m \lambda_m$. So the incoming traffic rate per host is $(\pi R^2 \delta - 1) \lambda_m L_m$ and the average numbers of packets in the queue per host are: $N_m = \frac{\left(\pi R^2 \delta - 1\right) \lambda_m L_m}{\left(\pi R^2 \delta - 1\right) \lambda_m L_m}$

In the above equation, the key parameter is $L_m$ and if $L_m > L_{\text{max}}$, then using a load balancing mechanism is no longer useful. Hence $L_m < L_{\text{max}}$.

**Theorem 6.1:** The traffic for a host located at a distance $r$ from centre of the disk can be expressed by the following expression-
\[ \lambda(r)=(\pi R^2 \delta - 1) + \frac{\pi (R^2 - r^2)^2 \delta^2 \beta}{2} \]

{Proof of the Theorem is in Appendix C}

**Step 1: Overhead due to route discovery**

**1.1 Overhead generated due to RRQ in multi path used by MAs**
We have assumed that \(N\) hosts broadcast a RRQ \(\lambda_m\) times per second, then the total overhead generated due to RRQ is \(S_{r_q} \lambda_m N^2\), where \(\lambda^\prime\) is calculated by Theorem 6.1.

**1.2 Overhead generated due to RRP**
In case of multipaths route reply packets follows \(L_m\) hops return back to source. So destination host replies to \(N'\) RRQ, so the overhead due to RRP is \(S_{r_p} \lambda_m L_m N'N\).

**1.3 Overhead generated due to ERR**
When a link is broken, an error packet is sent back to source to acknowledge the link breakage. Also \(L_e\) is the average length of the path from broken link to source \(\zeta_e < L_m\). Since the error packet has to travel \(L_e\) links to source, this produces \(L_e\) error packets per route broken. Since link breakage rate is \(\mu\), route breakage rate for a route with \(L_m\) links is \(\mu L_m\). Also for each host the average numbers of active routes are \(A'\), so each host route breakage rate is \(\mu L_m A'\). Hence in a network of \(N\) hosts, average overhead due to error packet is \(N' \mu L_m A' L_e N S_e\).

**Step 2: Overhead due to Data Transmission with load balancing**
Assuming that each data transmission is completed in \(T\) seconds and route discovery rate is \(\lambda_m\), interval between each route discovery is \(\frac{1}{\lambda_m}\), hence actual time for data transmission is \(\left(\frac{1}{\lambda_m} - T\right)\) sec. The number of data packets
sent during this interval are \( \left( \frac{1}{\lambda_m} - T \right) e \). So data packets are sent with an average rate of \( \lambda_m \left( \frac{1}{\lambda_m} - T \right) e \) packets/sec.

Also each data packet has to travel \( L_m \) hops to destination, so total overhead due to data transmission is \( \lambda_m \left( \frac{1}{\lambda_m} - T \right) e L_m P \)

Now total overhead is \( O_m = \text{Overhead of RRP} + \text{Overhead of RRQ} + \text{Overhead of ERR} + \text{Overhead of data transmission} \).

Although there is considerable amount of overhead generated using RLBMA algorithm, but it is still effective to achieve higher PDF comparison to other approaches. This is due to selection of host disjoint multipaths from a source to destination.

6.3 Implementation

We have tested RLBMA on Glomosim [166], with MANET topologies consisting of 50 wireless hosts moving under a nominal bit rate of 2 Mbps. MAs movement is controlled by PMADE [2]. Each run of the RLBMA is characterized by pause time. Each host selects a destination from the rectangular space randomly, and starts moving towards the target with a speed uniformly between 3- 5 m/sec. A CSMA technique with collision avoidance (CSMA/CA) is used to transmit packets from source to destination. Three performance metrics are evaluated in simulation:

- PDF – PDF is the ratio of the total number of data packets received by destinations over the total number of data packets transmitted by sources.
- Average end-to-end delay – The average end-to-end delay is the average of delays for all received data packet from the sources to destinations.
- Normalized routing load – The normalized routing load is defined as the total number of routing control packets transmitted by the total number of received data packets.

6.4 Result and Discussion

Figures 6.2 and 6.3 present PDF with variations in the pause time for RLBMA, AODV, and DSR. With 30 and 40 data sources, RLBMA outperforms AODV and DSR. In fact, RLBMA achieves up to 22% higher PDF than both AODV and DSR for both data sources. This is mainly because of redundant route information stored in destination host to provide aid in routing.

![Figure 6.2: Packet Delivery Fraction for 30 sources with DSR, AODV, and RLBMA](image_url)
Figure 6.3: Packet Delivery Fraction for 40 sources with DSR, AODV, and RLBMA

Figures 6.4 and 6.5 present comparison of end-to-end delay of RLBMA with DSR and AODV. RLBMA has a better average end-to-end delay than both AODV and DSR. For 30 and 40 sources, RLBMA achieves significantly lower delay than AODV and DSR. Moreover, the delay decreases with lower mobility in RLBMA for all cases while it increases with 30 and 40 data sources with higher mobility for both AODV and DSR. This is due to the high level of network congestion and multiple access interference in certain regions of MANET. But neither AODV nor DSR has any mechanism for load balancing, i.e., for choosing routes in such a way that the data traffic can be more evenly distributed. In contrast, RLBMA adopts a mechanism for load balancing, which tries to route packets along a less congested path to avoid overloading of hosts.
Figure 6.4: Average End-to-End delay for 30 sources with DSR, AODV, RLBMA

Figure 6.5: Average End-to-End delay for 40 sources with DSR, AODV, and RLBMA
Figures 6.6 and 6.7 present normalized routing load. The results obtained show that the routing load increases with increase in number of sources. This is because the increase in the number of source hosts causes a large number of request messages flooding from source to destination. RLBMA have a lower routing load than both AODV and DSR. AODV and DSR only accept the first request message at every host, i.e., if a host has already seen a request message for a particular packet, it will not accept a second message of the same packet. On the other hand, RLBMA accepts request messages as long as they are not looping through the host. Destination hosts keep a record of different route information from request messages as backup for use during the path maintenance. Therefore, RLBMA will almost always have an alternative path to route packets in case of link failure. This enables RLBMA to achieve higher PDF and lower average end-to-end delay.

Figure 6.6: Normalized Routing Load for 30 sources with DSR, AODV, and RLBMA
6.5 Summary

In this chapter, we have implemented MA based routing and load balancing mechanism called RLBMA on SFLBMS. Each path is associated with short term and long term rating. Whenever the rating of the path falls below predefined threshold that path is discarded from the set of available paths. RLBMA operates in two steps- route discovery and data transmission with load balancing. MAs are selected to execute the designed algorithm for route discovery and load balancing. RLBMA achieves up to 22% higher PDF than both AODV and DSR. Also RLBMA has a better average end- to- end delay than both AODV and DSR. RLBMA achieves significantly lower delay than AODV and DSR. RLBMA have a low routing load than both AODV and DSR. Also when compared with [167, 168, 169,170], RLBMA will almost always have an alternative path to route the packets in case of link failure.
This enables RLBMA to achieve higher PDF and lower average end-to-end delay.

In the next chapter, we will deal with service discovery in MANET.