CHAPTER 3

NODE STABILITY BASED CLIENT ROUTING FOR 802.11S NETWORKS

INTRODUCTION

This chapter presents a novel routing algorithm for IEEE 802.11s based Wireless Mesh Networks (WMN). The HWMP uses the Air Time Link metric to find the best path. The Air time Link metric outperforms the hop count in a mono channel mono radio environment. But it does not perform well in all scenarios and is affected by path instability and the broadcast storm problem (Ghannay, 2009).

In this chapter, a new node stability based client routing protocol (NSCRP), which reduces the path instability problem significantly, is proposed. The NSCRP identifies new routes by considering the stable nodes, the Air time link metric and the hop count, whereas the default routing protocol HWMP, uses only the ALM to route the packet. The routing accuracy of NSCRP based routing is comparable with the existing on-demand protocols and the HWMP protocol. The network throughput and the packet delivery rate of the NSCRP are higher than those of the other protocols. The average end-end delay and packet loss rate are lesser compared to the HWMP and the AODV protocols. The performance of this routing algorithm with respect to the throughput, packet delivery rate, average end to end delay and control overhead is compared with similar parameters of the AODV and HWMP. The simulation results show that this algorithm maximizes the
throughput and PDR, and minimizes the drop rate and the average end to end delay. Also, the results prove that this protocol is more promising for WMNs.

3.1 MOTIVATION

The main idea behind this routing algorithm is triggered by the routing procedure in partial infrastructure networks. All the existing routing protocols of MANETs can be applied to the WMNs also. But all the MANETs routing algorithms are designed for mobile nodes. The HWMP and RA-OLSR, the default routing protocol of IEEE 802.11s mesh networks are also derived from the existing adhoc protocols. But they fail to utilize the partial infrastructure feature of the WMNs. The above mentioned algorithms (HWMP and RA-OLSR) deal with both stable nodes and mobile clients in the same way. But the proposed algorithm differentiates the stable nodes and mobile clients, to make the routing more stable and efficient. The NSCRP considers the stable path, the shortest path and the link quality together, to select the best path.

3.2 AIRTIME LINK METRIC BASED ROUTING

The default routing metric of HWMP is the airtime metric, where the individual link metrics are added to get the overall path metric. The amount of channel resources consumed to transmit a frame from one node to another through a particular link is represented by the ALM. (Zhang 2006). A new path metric field is included in the RREQ/RREP message that contains the cumulative value of the link metrics of the path so far. The path with the smallest sum of airtime link metrics will be considered as the best path.

Figure 3.1 below illustrates how the airtime metric provides an efficient path through the network, considering the data rate, radio type and frame error probability. All airtime metrics given below include the radio type
on each link. Based on the airtime metric obtained, a stationary node is able to select a path towards the destination at the least total airtime cost. The source node C wants to transmit the packet to the destination E. In hop count based routing, the path will be selected through R since it has only two hops. But in ALM based routing, the individual cost of each link will be updated in the ALM field of the RREQ packet. The destination will check the final cumulative value of each received RREQ packet, and select the route which has the minimum link cost. In this case, the link C-F-G-E has the minimum link cost of 2373 compared to the other routes. The link cost of a two hop route C-R-E is 2540. So it is rejected and the lowest link cost path is selected.

![Figure 3.1 ALM based Routing](image_url)
3.3 NODE STABILITY BASED CLIENT ROUTING PROTOCOL (NSCRP)

NSCRP considers the hop count, the number of stable nodes and the link quality, to select the path from any given source to the destination. MAP, MP and MPP are considered as the stable nodes in the IEEE 802.11s network. The path through stable nodes will always be more stable than the path through the clients. Hence, the NSCRP gives preference to the path with more stable nodes.

3.3.1 Algorithm

Whenever a source node has data to transmit, the following steps are executed.

1. The source node initiates route discovery by broadcasting the RREQ packet.

2. The nodes receiving this route request packet will check if it is the intended destination or not.

3. If so, a route reply RREP is unicast to the destination.

4. If the packet is received by stable intermediate nodes, it will update all the mutable fields except the hop count field.

5. If the packet is received by the client node, it will update the hop count field and the mutable fields. The node cost will be the difference between the number of hops and the number of stable nodes in the route.
6. If the destination receives RREQ from multiple paths, the destination will calculate the link cost from the cumulative link metric field, and the node cost from the node cost field.

7. The destination will select the best route from the path cost, and then the RREP will be unicast to the source by the destination.

8. The data packets are transmitted through the selected best path.

Figure 3.2 shows the path chosen by the HWMP and the path chosen by the proposed NSCRP. The NSCRP selects the best path which has the minimum hop count through stable nodes and the best link at the minimum ALM cost.

![Figure 3.2 NSCRP Based Routing](image-url)
Figure 3.5 shows the flow of the NSCRP protocol. The NSCRP will select the optimum route, by identifying a route with more number of stable nodes, low air time link cost and less hop count. As given in equation 3.2, the client node which needs to transmit the data to the destination, should first get associated with the MAP. After the association with MAP, it becomes a mesh client, and can route the packet to the destination by identifying the best path. For routing, the source will broadcast the RREQ packet to its neighboring nodes. The RREQ packet will have both a link metric field and a node cost field.

The node cost will be calculated by considering the number of hops and the number of stable nodes in its path. The node cost is the cost spent to reach the destination through the stable nodes. The link cost field will be updated, depending upon the ALM value. At the destination, it will process the received RREQ packet. The destination will calculate the path cost using Equation 3.1, and select the optimum route using Equation 3.2, and reply to the source.
Figure 3.4 RREP Packet

Figure 3.3 and Figure 3.4 shows the frame formats of RREQ and RREP packet. Link Cost calculated using ALM field and Node cost calculated using hop count field.

Path Cost = $L_i \times N_i$ \hfill (3.1)

Link cost $L_i = [O_{ca} + O_{p} + (B / r)] (1/1 - e^{pt})$

where

$O_{ca}$ - represents the channel access overhead

$O_{p}$ - represents the protocol overhead

$B$ - represents the number of bits in a test frame.

$N_i$ = node cost

Optimum Route = $\text{Min} [ \sum L_i \times N_i]$ \hfill (3.2)
Figures 3.5, 3.6, 3.7 and 3.8 show the way in which the NSCRP handles the RREQ, RREP, Data and RERR packets respectively.

Figure 3.5 Procedure to handle RREQ Packet
If the node is an intended destination, it generates a route reply (RREP) and unicasts the RREP packet back to the source in a reverse path. If the intermediate has a valid path to the destination, it issues a RREP to the source depending on the destination only flag. The procedure to handle the Route Reply Packet is shown in Figure 3.6.
After the route discovery process, the data transfer starts between the source and the destination as shown in Figure 3.7. When a link breaks due to mobility, interference or attenuation, the edge node of the broken link identifies it and generates a route error (RERR) packet towards the source.
node as shown in Figure 3.8. A node receiving a RERR invalidates the corresponding entries in its routing table and initiate route discovery to recover the failed link or to find a completely new path by considering new stable nodes that is different from the previous one.

Figure 3.8 Procedure to Handle Route Error Packet
3.4 DATA STRUCTURES

The mesh nodes are required to maintain the following data structures while using the node stability based routing protocol.

**Node cost Table**

This table will maintain the node cost of each path. The node cost is the cost spent to reach the destination through the stable nodes. It will be the difference between the number of stable nodes and number of hops between the source mesh node and the destination mesh node.

**Path Cost Table**

This table will maintain the path cost calculated by the destination node for each available route. The path cost is the product of the cumulative link cost and the calculated node cost.

Path Cost = \( L_i \times N_i \)

where \( L_i \) = link cost

\( N_i \) = node cost

3.5 PERFORMANCE EVALUATION

The proposed node stability based client routing algorithm is simulated, and the performance of the protocol is evaluated. The network throughput, average end-to-end delay and the protocol overhead with respect to the network traffic are studied and the results are presented in this section. These parameters are compared with the existing AODV and HWMP protocols.
The following metrics were used in computing the protocol performance.

**Packet Delivery Ratio:** Measured as the ratio of the number of data packets delivered to the destination and the number of data packets sent by the source.

Packet delivery ratio $= \frac{N_r}{N_t}$

where $N_r$ is the number of packets successfully received, $N_t$ is the number packets transmitted.

**Average End–End Delay:** Measured in ms as the time between the reception of the last and first packet / total number of packets reaching the application layer. This delay includes processing and queuing delays in each intermediate node.

**Throughput:** Measured as the ratio of the number of data packets delivered to the destination and the number of data packets sent by the sender per second.

**Routing Overhead:** Measured as the number of control packets transmitted during the simulation period.

Routing overhead (RO) $= N_Q I_Q + N_R I_R + N_E I_E$

Average control overhead (RRO) $= \frac{RO}{I_T}$

where $N_Q$ is the number of RREQ packets, $I_Q$ is the length of the RREQ packet, $N_R$ is the number of RREP packets, $I_R$ is the length of the
RREP packets, \( N_E \) is the number of RERR packets, \( I_E \) is the length of the RERR packets and \( I_T \) is the total length of the transmitted data.

### 3.6 RESULTS AND DISCUSSION

A network comprised of stable nodes and mobile clients, placed randomly within a 1500*1500 meter square area, is simulated. The radio propagation range of 250 meters was chosen for each node. Multiple runs with different initial values were conducted for each scenario, and the collected data were averaged over those runs. Figure 3.9 shows the simulation environment.

Table 3.2 lists the simulation parameters and environments, which are used as default values unless otherwise specified.

**Table 3.2 Simulation Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain Range</td>
<td>1500*1500 square</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>250 m</td>
</tr>
<tr>
<td>Node Placement</td>
<td>Random</td>
</tr>
<tr>
<td>Mobility Model</td>
<td>Random Way point model</td>
</tr>
<tr>
<td>Propagation Model</td>
<td>Two ray</td>
</tr>
<tr>
<td>Station Association Type</td>
<td>Dynamic</td>
</tr>
<tr>
<td>MAC type</td>
<td>802.11s</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Number of mesh points</td>
<td>10,20,30,40,50,60,70</td>
</tr>
<tr>
<td>Number of mesh clients</td>
<td>3,6,9,12,15,18</td>
</tr>
<tr>
<td>Data payload</td>
<td>512 bytes</td>
</tr>
<tr>
<td>Routing protocol</td>
<td>NSCRP</td>
</tr>
</tbody>
</table>
Figure 3.9 shows the simulation environment used in NSCRP protocol.

![Diagram of simulation environment]

**Figure 3.9 Scenario used for simulation**

**Medium access control**

The IEEE 802.11s protocol with distributed coordination function is used as the MAC layer. DCF is the basic access method used by mobile nodes to share wireless channel under independent ad hoc configuration.

**Traffic pattern**

A traffic generator is developed to simulate CBR sources. The size of the payload is 512 bytes. This value is chosen because small payload sizes penalize protocols that appended routes to each packet. Data sessions with randomly selected sources and destinations are simulated. Each source transmits data at a rate of 2-10 pks/sec.

**Propagation model**

Two ray propagation model is used in these experiments. In these model the signal power attenuates as 1/d² where d is the distance between
radios. In addition, the capture effects in radio model are taken into account. If the captured radio, which is defined as the minimum radio of the signal strength of arriving packets relative to those of other colliding packets, is greater than the predefined threshold value then, the arriving packet is received while other interfering packets are dropped.

A network of 75 nodes placed randomly within a 1000*1000 meter was simulated. The radio propagation range of 250 meters and channel capacity of 2Mb/s was chosen for each node. Each simulation was made to run for 10 minutes. Multiple runs with different seed values were conducted for each scenario and data obtained were averaged over those runs.

Figure 3.10 shows the effect of the number of CBR connections on the average end-to-end delay. The average delay performance of NSCRP is compared with the HWMP and AODV protocols.

![Figure 3.10](image)

**Figure 3.10** Effect of the Number of CBR connections on Average End–to-End Delay
The initial latency of the HWMP was very high. The NSCRP based routing produces 5ms less latency than the AODV. So the NSCRP performs well compared to the HWMP and AODV.

![Figure 3.11 Effect of the Number of CBR connections on the Average Throughput](image)

**Figure 3.11 Effect of the Number of CBR connections on the Average Throughput**

The effect of number of CBR connections on the average throughput is shown in Figure 3.11. The throughput performance of the NSCRP is compared with that of the AODV and HWMP.

The results indicate that the NSCRP has a lower packet loss rate than the AODV and HWMP under increasing traffic loads. This is essentially due to the routing of packets through the stationary nodes. The throughput of the NSCRP scheme is found to have improved by 18% as compared to the
HWMP and 10% as compared to AODV. It is also observed that the NSCRP is able to maintain a good throughput performance.

![Figure 3.12](image.png)

**Figure 3.12 Effect of the Number of Nodes on the Average Control Overhead**

Figure 3.12 shows the effect of the number of nodes on the protocol overhead. The proposed routing algorithm NSCRP is compared with the HWMP and AODV protocols.

When the traffic load is increased, the control overhead of all the protocols increases. Since the NSCRP does not use more control packets for the routing through stable nodes, the control overhead of HWMP and NSCRP is more or less identical to each other. Since the NSCRP uses three metrics to select the path, the protocol overhead is slightly higher in the NSCRP than in the AODV.
Figure 3.13  Effect of the Number of Nodes on Average Throughput

Figure 3.13 shows the effect of the number of nodes on the average throughput. The throughput performance of the NSCRP is compared with the HWMP and AODV.

The throughput of NSCRP is higher than that of the HWMP. This is due to the fact that the stable nodes also participate in routing, which reduces the packet drop. But, for the HWMP, the throughput is slightly less. This is because the HWMP does not select a path based on stable nodes, and uses only the ALM for the optimum path. But both the protocols face throughput degradation, as the number of nodes increases due to the scalability issue.
The average end-to-end delay performance, as the number of nodes increases is shown in Figure 3.14. The NSCRP protocol is compared with the HWMP and AODV.

The average end-to-end delay is less for the NSCRP than for the HWMP. The delay increases as the number of nodes increases. This may be due to a longer route discovery latency and path length. The HWMP considers only the ALM to find a path, and it is affected by the path instability issue. But the NSCRP considers the path cost for routing, and in turn utilizes the stable path. Hence, the time taken by the NSCRP is less than that by the HWMP to reach the destination, as the number of nodes increases.
Figure 3.15  Effect of the Mobility on Average Throughput

Figure 3.15 highlights the effect of mobility on the average throughput in wireless mesh networks. The performance of the proposed NSCRP is compared with those of the HWMP and AODV protocols.

The throughput performance of the HWMP and AODV degrades, as the speed of the client node increases. This is due to the frequent link failure in a mobile environment. Client speed will not have much impact on the NSCRP, as it gives preference to select a path through stable nodes. So, the throughput of the NSCRP is higher than that of the HWMP and AODV.
Figure 3.16 Effect of the Mobility on Average Control Overhead

Figure 3.16 illustrates the effect of the mobility on the performance of the average control overhead. The control overhead of the NSCRP is compared with the existing AODV and HWMP protocols.

Overhead of the NSCRP is slightly higher than that of the AODV and HWMP. As the client speed increases, the control overhead also increases. The improvement in the PDR is achieved at the expense of minimal excess control overhead.
Figure 3.17 Effect of the Mobility on Average End – End Delay

Figure 3.17 highlights the average end-to-end delay performance of the three protocols. The delay is lesser for the NSCRP compared to the AODV and HWMP. This is because the NSCRP selects a stable path from the available paths for transmitting a data packet to the destination. So the increase in the client speed will have a lesser impact on the NSCRP than the HWMP and AODV.

The NSCRP outperforms the HWMP in all scenarios, since the HWMP considers the link loss rate and link bandwidth when selecting a path.
3.7 SUMMARY

In this chapter, the performance of the existing routing algorithms like the AODV and HWMP is compared with that of the proposed protocol NSCRP. All the current routing algorithms suggested for IEEE 802.11s WMNs consider the hop count or the ALM to find the best path to the destination. The concept of node stability based client routing is proposed, and the simulation performances of the NSCRP, AODV and HWMP algorithms are presented in this chapter.

From the results obtained, it is understood that networks like MANETs in which all the nodes are mobile, can use the existing protocols such as the AODV and DSR. But WMNs which are partially infrastructure based, should use routing protocols in which the routing metric should utilize the stability of the network. So the NSCRP would best suit WMNs, which have both stationary nodes and mobile clients.

From the obtained results, it is observed that both NSCRP and HWMP suffer from the scalability issue. The scalability issue for the multihop routing protocols is mostly concerned with excessive routing message overhead caused by the increase in the network population. So, a scalable and load balanced routing protocol for IEEE 802.11s networks is proposed in chapter 4.