Congestion Avoidance Hybrid Wireless Mesh Protocol (CA-HWMP) for IEEE 802.11s

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Abstract

To support the mobility and low cost deployment, the wireless technology is being used for number of applications. Wireless Mesh Networks (WMN) is one of the evolving technology to provide un-disrupted data connectivity to mobile users. It provides high bandwidth through efficient resource sharing, specially for areas deprived of wired connectivity. These networks also offer self-configuring, self-healing and self-organizing capabilities. IEEE 802.11s is a MAC standard being proposed as an enhancement for WMN. This standard includes the use of a mandatory routing protocol at MAC layer, known as Hybrid Wireless Mesh Protocol (HWMP). However, HWMP offers weak response to congestion, especially for interactive applications. IEEE 802.11s has also proposed sharing of Congestion Control Notification Frame (CCNF) on reaching congestion threshold. In this research paper, we have proposed a congestion avoidance technique named Congestion Avoidance Hybrid Wireless Mesh Protocol (CA-HWMP). The proposed technique offers localized re-routing based upon congestion threshold, with minimal overheads. The re-routing decision is taken by each node using CCNF received from the next hop neighbor. The proposed algorithm do not add any overhead as the CCNF is already the design part of 802.11s. This paper also shows comparison of proposed technique against HWMP under NS3 for the validation of proposed idea. From the comparison we concluded that use of CA-HWMP as replacement of HWMP significantly improves the performance of IEEE 802.11s.

1. INTRODUCTION

Nowadays wireless technologies are used in many strategic and low cost e-applications. IEEE 802.11 variants are available widely and are very common for WLAN scenarios. The ongoing research on wireless technology focuses on military applications and some specialized civilian applications. Users are more interested in general purpose applications where high bandwidth and internet connectivity is in their high priority. Therefore, a new multi-hop wireless network type has emerged in the market which has advantages of both ethos multi-hop and broadband access and is
called Wireless Mesh Network (WMN).
WMN is a propitious technology due to its quite low cost of deployment and connectivity of wireless broadband. It is also deployed in rural areas to provide broadband services because of it reduced cost of deployment. There are many applications which are efficiently supported by WMN. It is also used in building automation control, emergency and safety applications due to its self-healing, self-configuring and self-organizing capabilities. WMN solutions provided by different organizations. WMN is one of the important technology for next generation wireless networking due to some of its advantages over other wireless networks. WMN can be infrastructure backbone WMN, client WMN, or Hybrid WMN. Infrastructure/backbone WMN provides backbone access to the conventional clients and also provides integration with existing networks.

IEEE 802.11s two-tier mesh network consists of backhaul and access tier. Communication between mesh nodes is represented as wireless mesh backbone/ backhaul while communication between wireless mesh nodes and clients to the clients is called an access-tier. The mesh routers forward traffic on behalf of neighbor nodes like in multi-hop adhoc network.

In IEEE 802.11 standard, adhoc mode nodes can connect each other without any central entity or coordinator such as an Access Point(AP). There are many interesting applications where adhoc mode is not sufficient to fulfill the requirements, like support of internet connectivity and presence of client nodes. Therefore, both types of modes i.e. infrastructure and adhoc are integrated in a new type of wireless network, named as Wireless Mesh Network. IEEE developed the IEEE 802.11s standard for multi-hop WMN whose final draft was released in September 2011. IEEE 802.11s inherently depends upon one of the IEEE 802.11 variants like a, b, g, and n for multi-hop WMN.

WMN is a combination of IBSS and ESS advantages. There are three types of nodes involved. Mesh point(MP) acts as a relay station and does not have AP functionality. MPs connect to one another with wireless links. Therefore internal wireless mesh LAN is not an ESS. Another type is Mesh Access Point(MAP) which has AP functionality in addition to MP functionality. Station nodes associate themselves with MAP. The third type of node is Mesh Portal(MPP) which also have MP functionality and is a point where MSDUs enter or exit WMN to other network. IEEE 802.11s MAC is the extension of existing IEEE 802.11 MAC, having some additional functionality like routing protocol is handled at MAC layer whereas layer 3 routing protocols are needed at MPP for path selection while communicating with other networks.

IEEE 802.11s MAC also includes functions for QoS (performing priority Control), congestion control and admission control, a function for achieving spatial frequency reuse, a function for performing preventing degrading performance due to expose and hidden problems. While working on congestion control, some researchers consider its queue mechanism, link capacity and routing protocols. As path selection mechanism is handled at the MAC layer, therefore may also be handled congestion at MAC layer. In the wireless congestion scenario, packet lost or queue overflow are caused by wireless communication issues e.g. greater error rate due to wireless channel, wireless bandwidth etc. In wireless, one node sends data at a time due to shared characteristics of the wireless channel. The increase in packets delay and queue length leads to congestion. IEEE 802.11s does not specified any congestion control mechanism. However, various congestion control techniques are proposed in literature to resolve this problem which have their own pros and cons. In this paper, we proposed a novel idea to avoid congestion mechanism to address this problem which increase the network throughput.

2. LITERATURE SURVEY

In a WMN, traffic aggregated at the portal nodes. In case of the greater traffic load, MPs on the outer edges of the network suffer low throughput and greater packet loss in the absence of any congestion control mechanism. The standard draft outlines an optional congestion control mechanism known as hop-by-hop congestion control mechanism. There are basically three steps used in hop-to-hop congestion control mechanism as mention in the draft. In first step each MP in the WMN monitors its congestion rate. For monitoring, the mesh node may use the queue size as metric to identify the congestion or minimize the queue size by regulating the incoming and outgoing data rate. In second step when the transit queue level reaches at the specific level, Congestion Control Notification Frame (CCNF) broadcast to immediate nodes. On receiving the CCNF frame, the entire immediate node limit their data rate based on service differentiation criteria. CCNF frame also contains an expiry time for this notification. A mesh node may also send a congestion control request to the selected nodes to limit their data rate according to channel rate. In the third
step. Upon receiving congestion notification frame, the nodes limits their traffic rate. In\textsuperscript{7} proposed a distributed adapted mechanism with the hop-by-hop feedback of congestion information. The proposed technique is for WMN with multi-channel MAC, having two NICs on a single node at the same time. Both NIC’s operate independently. They first derive end-to-end algorithm, then further develop hop-by-hop congestion control algorithm which control the source rate directly. The limitation of the proposed technique is that it uses a feedback mechanism which increases control messages in the network. The combination of two algorithms for congestion control increases processing cost on each node too and every node must require two NICs. In\textsuperscript{15} coordinated congestion control algorithm is proposed to provide end-to-end max min fairness for each flow. This algorithm is designed for both inter-flows and intra-flows and work with multi-hop wireless link. According to the author a gateway can act as central coordinator to perform traffic engineering. Similar fair share congestion control problem is discussed in\textsuperscript{2}. These algorithms are fit in unfair channel sharing scenarios. Unfair channel sharing can also lead to congestion. However, Considering these fair share algorithms in those scenarios where a network is congested due to high arrival rate, then we require a technique which reduces the arrival rate on a specific node rather apply a bandwidth share algorithm on a specific node. Ultimately a node can receive and forward data up to its maximum capability limit.

WCP\textsuperscript{14} is a source base congestion control algorithm in which for every flow, the source node maintains rate. This rate represents the sending rate of the specific flow. WCP uses the phenomena of Additive increase and multiplicative decrease (AIMD). It estimates the neighboring node capacity and then share it among contended nodes. This mechanism is called WCPCap. Still if a node receives data from multiple nodes and forwards to other nodes, the problem will remain same. In multi-hop WMN, there is possibility of alternate path. A node can forward data at the same rate using alternate path. Also this algorithm is proposed for IEEE 802.11 MAC and no routing is handled at MAC layer for multi-hop WMN. As each node maintain rate for each flow, and every node in the WMN is the router, therefore more delay added. In the same scenario battery conception is another weak point.

Different algorithms were devised for congestion control to provide solution for different issues of intra mesh congestion scenarios using congestion notification. Total Congestion Control (TCC) and Link Selective Congestion Control (LSCC)\textsuperscript{9} were proposed which resolved some issues but in some scenarios their algorithms do not work well. While using TCC, the total traffic was blocked for the congested node on receiving CCNF. This frame is broadcast by a node whose queue is full due to congestion. In LSCC algorithm, on receiving congestion notification, it limits the traffic for specific link by blocking the data packets for a specific node. In Path Selective Congestion Control (PSCC)\textsuperscript{19}, on the receiving of CCNF, nodes only block the data frame for specific destination. In PSCC, congested node broadcast CCNF to limit the traffic for specific destination. The congested node provides this information by adding a destination address for a specific flow into CCNF. For the announcement of specific destination, this algorithm requires modification in the standard CCNF. On receiving modified CCNF, a node only blocks sending data for a specific destination, but it continuously receives data for that specific node. The scenario becomes more complicated when CCNF frame is further broadcast to immediate node in a continuous chain. These algorithms resolve congestion problems in some scenarios of multi-hop WMN uses IEEE 802.11s MAC.

In a mesh network, due to the use of multimedia or interactive application on internet, MPs near to MPP have greater traffic, therefore greater chances of congestion at the MPs near to the MPP. When congestion occurs, packets drop from queue regardless of the number of hops the packets already have traversed. To resolve this problem, we proposed another technique which avoids the congestion rather than control the congestion in order to reduce packet loss and improve network throughput.

3. Proposed Mechanism

Congestion Control technique or algorithms apply when congestion has introduced into the network. Our proposed technique focused on the congestion avoidance rather on congestion control. In our proposed technique, as we are working on WMN where path selection is performed at the MAC layer, therefore we utilize its mandatory protocol for congestion avoidance. Our proposed routing protocol Congestion Avoidance-Hybrid Wireless Mesh protocol (CA-HWMP) is the modification in the current mandatory routing protocol HWMP for IEEE 802.11s monitor queue size at every node. The basic information elements used in the proposed mechanism are same as used in the HWMP i.e. PREQ, PREP, PERR, RANN (Root Announcement). In the proposed routing protocol, when the queue size at node B reached at specified queue value and it check the maximum virtual buffer size, then it broadcasts the CCNF frame.
to its neighbors. All the neighbor nodes, who send data through node C, will send PREQ to find the new path to the
destination excluding the existing paths through node C. re-routing reduce traffic load at a specific link/node. The
remaining traffic forwarded to the destination using the new calculated path. This mechanism, not only reduce the
congestion problem but also load balance in the multi-hop WMN.
Considering a scenario given in Figure 1, in which node A, F and C are in the neighbor of node B. Node G and H are
in the neighborhood of A. Node G sends data to node C, the optimal path selected by its routing protocol HWMP is
\[ G \rightarrow A \rightarrow B \rightarrow C. \]
The link between B and node C is congested. As proposed routing protocol monitors the queue size at the every mesh node. At node C, when its queue size reaches the specific queue size threshold, then routing protocol at node B broadcast CCNF frame to its neighbor list. Neighboring nodes who receive CCNF, send PREQ to calculate a new path for the desired destination. All the immediate nodes in the node A receive the PREQ and check their queue status, if the receiving node has already reached at the specific queue specified value then it will ignore the PREQ, otherwise it forward or reply according to the flags setting on the PREQ frame. In the current given scenario, node G, node H, node C and node F received the PREQ. Node C, ignored the PREQ in case it received the PREQ frame anyhow. The next step is that the receiving mesh node like mesh nodes also forwarded PREQ frame to their neighboring node. The procedure was continued until the destination node reached and sent PREP. The new route built from source mesh node G to destination node will be in the given scenario is \[ G \rightarrow A \rightarrow F \rightarrow I \rightarrow C. \] The data packet that was queued in the absence of congestion avoiding protocol, will now forward to destination node using this new established path. This mechanism reduces the packet lost which was taking place due to queue overflow. This protocol allows the data transmission on the alternate route instead to wait the positive signal of congestion to restart transmission on existing track.

3.1. Proposed Algorithm

The proposed technique CA-HWMP which is basically a modification in original default protocol of IEEE 802.11s i.e HWMP. The procedure is that when a node have data to send to other node, it broadcast the PREQ to its immediate node. The receiving nodes forward the PREQ according to basic rules of the default protocol and additional to that they will check their queue level. If it is below to the defined value, it forwards PREQ to other nodes. Finally, when the PREQ source node receives PREP, the path will establish. Here is the modified algorithm of the proposed routing protocol for IEEE 802.11s;

Fig. 1. Proposed CA-HWMP protocol Mechanism
Variables

1: SourceNodeData: Boolean variable for source node data status, it is 1 for true and 0 for false
2: QueueMax: Queue maximum value
3: PREQ: Path Request
4: PREP: Path Reply
5: Path: one hop path
6: TO: Target Only flag
7: RF: Reply and Forward
8: SequenceNum: PREQ message sequence number
9: ownSequenceNum: sequence number saved at intermediate or destination node

(main Algorithm)

11: If((SourceNodeData == true)||(QueueMax => 65%))
12: Then Source node broadcast PREQ
13: upon receiving PREQ if(QueueMax <= 55%)
14: Then ignore the PREQ message
15: elseif(SequenceNum > ownSequenceNum)
16: Then update Path
17: if(New Path created or Modified)
18: Then forward PREQ

(Flags)

19: TO = 1: only destination send PREP
20: TO = 0andRF = 0: intermediate node send unicast reply to source with Path and does not forward PREQ
21: TO = 0andRF = 1: The first intermediate node with the Path sends reply to source, change TO=1 and forwards PREQ

4. Simulation and Results Evaluation

For the performance evaluation of IEEE 802.11s, NS3 provides its module implementation and functionality support. As this simulator is open source and provides the flexibility of implementation of new protocols into it. By taking advantages of it and to evaluate our proposed protocol CA-HWMP, we patched it successfully into mesh module of NS3 using C++.

Table 1 describes the general simulation parameter of the scenarios of IEEE 802.11s. The simulation is performed on the Linux Distribution Fedora Core 13, the simulation tool used for our mesh scenario is NS-3.14. NS 3 have the built in support of IEEE 802.11s and provide the flexibility of the modification in modules. The application for our scenario is used On-off application (CBR application) which transmit data at a constant bit rate. Here we use its data rate varies from 100Kbps to 350Kbps on UDP transport layer protocol. For nodes topology we use nodes in grids where the number of nodes increase in both dimensions where separation between nodes is 170m.

For proposed idea validation and comparative analysis of both protocols, we have selected the effect of application data rate on throughput. We have considered multiple simulation scenarios by changing the number of node in the network. This variation provides the chances of variate alternate route availability. We choose the grid topology \((m \times n)\) in which each node in the topology acts also as relay station i.e. MP. In the grid topology \(m\) indicates the number of the nodes in the X-axis and \(n\) indicates the number of nodes in Y-axis. Initially, we use \(2 \times 2\) grid then increase value of \(m\) and \(n\) additive.

4.1. Effect of Application Data Rate on Throughput

In our scenario mesh grid topology is taken into account, where 50% nodes of the network generate traffic in the network. The choice of the source node and destination node is taken run time to make the scenario more realistic as happened in the network, only nodes which have data to send, try to access the channel. It is not necessary all the nodes in the network send data all the time. Here we restrict our traffic flows up to 50% so that we can observe
Table 1. General Simulation Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Operating System</td>
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<td>NS 3 version</td>
<td>NS-3.14</td>
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<td>Wifi Standard</td>
<td>IEEE 802.11s</td>
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<td>Mobility Model</td>
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<td>Disable</td>
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<td>Trace Module</td>
<td>Flow Monitor</td>
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<tr>
<td>Traffic Flows</td>
<td>Constant-bit rate (CBR)</td>
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<td>Flows Varies</td>
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<tr>
<td>Packet Size</td>
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<td>UDP</td>
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<td>HWMP, CA-HWMP</td>
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<tr>
<td>Number of Nodes in Grid</td>
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</tr>
<tr>
<td>Transmission Range</td>
<td>170m</td>
</tr>
<tr>
<td>Simulation Time</td>
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</tbody>
</table>

Fig. 2. (a) Throughput Comparison of HWMP and CA-HWMP at 150Kbps; (b) Throughput Comparison of HWMP and CA-HWMP at 250Kbps

the benefits of the alternate path available in network. To observe the effect of application data rate of throughput of the network, we run CBR traffic varies from 150Kbps to 350Kbps, node grid varies from 4 to 64 nodes and device maximum data rate limit is 350Kbps. We calculate the average throughput of the network. Graphs from Figure 2 (a) to (c) represent effect on throughput of the network at different node density and data rate. In the graph, the variation nodes in the grid are shown on X-axis where mesh grid varies from $2 \times 2$ to $8 \times 8$, while variation in throughput shown on Y-axis.

Consider Figure 2(a), where network behavior is shown in a scenario of 150Kbps application data rate while moving from sparse mode to dense mode. When there are 4 nodes in the network, all nodes are in the direct access, so all nodes can directly communicate each other. When the number of nodes increases from 4 to 9 in network, there is still less opportunity of alternate paths, therefore throughput observed in using both routing protocol is same. When the number of nodes increases to 16 in grid while using HWMP, the more intermediate nodes are available in forwarding data. This phenomena depend upon the source and destination node in the network. If intermediate nodes receive data from more than 2 nodes to forward then it will queue packets to forward. When queue becomes full, it drops packets from the queue. By increasing the number of nodes in the grid, this throughput degradation behavior increases while using HWMP. In case of 36 nodes in a grid, as the source and destination nodes are chosen run time, number of hops increases and due to multiple flows on intermediate nodes result in packets dropped from the queue. This packet drop ratio increase when more nodes enter in network to communicate. In case of 49 nodes in grid, throughput degradation effect increases. As we move from sparse mode to dense node, new entering nodes in the network generate more data to send/share with other nodes in the network. However there are some negative effect. By this movement of sparse to dense network there is a greater exchange of control messages to manage the network. There are also greater contentions for channel access which increases the chances of data collision, re-transmissions. As intermediate nodes forward data on the behalf of neighbor nodes and get congested due to greater data arrival rate and less forwarding rate. In this scenario packets drop from queue. When we use CA-HWMP instead of HWMP, as graphs line shows in Figure 2(b), we observed greater throughput as compared to HWMP because CA-HWMP. This is because CA-HWMP
takes advantage of alternate paths when an intermediate node in already selected path get congested. In case of 64 nodes in a grid, this gain is greater as greater alternate paths are available, while in case of 4 and 9 nodes its gain is zero due to two reasons. First, no alternate path available, and secondly there are less chances of the packet lost as almost all nodes can communicate directly or maximum one hop involved to forward data to the destination.

In the next step, we increase data rate to 250Kbps. The effect of data rate of throughput while we increase the number of nodes i.e. 4, 9, 16, 25, 36, 49 and 64 is shown in Figure 2(b). When we have 4 and 9 nodes in the network, we observed similar behavior of both routing protocols. But in case of a grid of 9 nodes, there is only a single node is at the junction of all remaining nodes. Therefore, the only node present in the junction of all nodes, when receives data from multiple nodes, initially it queues data and then eventually drop it from the queue. This results in degradation of throughput of the network. As there is less availability of alternate path and least number of nodes in the grid, CA-HWMP also performs badly. By increasing the number of nodes in grid from 9 to 16, more data discriminate in the network. However, there is also a chance of congestion at intermediate nodes which degrades throughput while using HWMP. This throughput degradation increases when more nodes enter in the network. We observed almost constant change in throughput although we have more nodes to send data in network as we increase the number of nodes in the grid. When we use CA-HWMP in the same scenario with the data rate of 250Kbps and number of nodes varies from 16 to 64, we observe better performance of it as compared to default routing protocol. This improvement is due to availability of alternate paths. CA-HWMP graph line shows that when we increase the number of nodes in a grid from 49 to 64, this improvement is almost equal to as we achieves in 49 node grid. This shows that benefits of alternate path have some limitation. Although an increase in the number of nodes in the grid also increases the availability of alternate path, but this increase in the number of nodes also increases the number of control messages, channel contentions and collisions.

To observe the effect of application data rate of throughput we set application data rate equal to the sending data rate of the device. We restrict application to send data at the rate of 350Kbps where the device sending data rate is also 350Kbps. In this scenario when the number of nodes in the grid varies from 4 to 9, both routing protocols perform same as we noticed in previous scenarios. When the number of nodes in grid vary from 9 to 49, CA-HWMP performs better than HWMP. This gain increases with the increase of the number of nodes in the grid. In this scenario, CA-HWMP gets the benefits of alternate paths, and re-route traffic on second optimal path when congestion occurs at intermediate nodes. We increase the number of nodes from 49 to 64 in the grid, throughput degrades while using HWMP protocol because due to the greater number of nodes, number of hops increases between source and destination. Therefore, the intermediate nodes that forward multiple node’s data, drop packets from queues due to greater arrival data rate as compared to forwarding data rate. CA-HWMP although is performed better but its performance is also affected by other factors like greater exchange of control messages, routing protocol messages and channel contention. Therefore, the CA-HWMP graph line in Figure 2(c), shows decline in throughput when we increase the number of nodes in grid 49 to 64. In 49 node grid, CA-HWMP performance is most significant.

To conclude the effect of application data rate of throughput of the network, it is observed that by increasing an application data rate throughput of the network also increases. This increase in throughput is limited to specific data rate and number of nodes in the network. At the 350Kbps data rate maximum throughput is observed when the number of nodes is 49 in the grid. All graphs show this trend that CA-HWMP performs better when the number of nodes in network are between 25 to 64. We observed the maximum gain at a 350Kbps data rate in the network of 49 node grid. This shows the limitation of the proposed routing protocol for congestion avoidance. In the presence of alternate path its performance is better but after a limited number of nodes its performance degrades.

5. Conclusions

Use of mobile wireless for the Internet is increasing at a rapid pace. Moreover, internet traffic pattern shows that users are more interested in the interactive applications. Among the evolving technologies, WMN is a wireless technology which provides high bandwidth and caters mobile users. It is a suitable candidate for network provisioning in the areas where connectivity through wired media is comparatively difficult or lengthy process. IEEE 802.11s is the first MAC standard being proposed for WMN and this standard includes a routing protocol at the MAC layer. HWMP is the mandatory protocol proposed by IEEE 802.11s, which offers the advantages of both reactive and proactive approaches. In wireless scenario, packet loss is generally caused due to wireless communication issues, such as
congestion or contention, etc. In IEEE 802.11 based wireless networks, but one node can transmit the data at a time, due to shared channel characteristics. This restriction adds a significant delay with the increment of the number of hops. The increase in packet delivery delay and queue length leads to congestion among wireless nodes. In a WMN, in case of the greater traffic load, traffic is aggregated at the portal nodes. As a result, in the absence of any congestion control mechanism, nodes at the outer edges of the network undergo low throughput and increased packet loss. To solve this problem many researchers have proposed algorithms but every technique have their own pros and cons. To handle congestion at the MAC layer, we proposed a congestion avoiding technique named Congestion Avoidance Hybrid Wireless Mesh Protocol (CA-HWMP). In this protocol, when node queue level reached to a specified threshold value, it broadcasts CCNF to its immediate neighbors. The nodes present in its neighbor re-route all traffic on congested node from alternate path. For comparison, we have selected our proposed approach using IEEE 802.11s WMN with its mandatory routing protocol i.e. HWMP. For performance evaluation, we used NS3. We evaluated our proposed protocol through throughput. We also noticed this effect on the different node grids by gradually varying the environment from sparse to dense mode. From the comparison we concluded that CA-HWMP performs better than HWMP in term of greater throughput. We will evaluate and compare its packet delivery ration and delay in the future work. This comparison can be made with default routing protocol and other existing congestion control protocols.

References