Link Quality-Aware Packet Forwarding Architecture for Wireless Mesh Network*

Hung Quoc Vo and Choong Seon Hong**
Department of Computer Engineering, Kyung Hee University
vqhung@networking.khu.ac.kr, cshong@khu.ac.kr

***Abstract* — Traffic engineering, as its name, is the art of manipulating traffic around so that traffic from congested links is moved onto the unused capacity on the other links. So, providing traffic engineering support in multi-hop wireless network has become increasingly important due to the low bandwidth nature of wireless channels. In this work, we propose a novel approach to control the traffic to avoid congestion by decoupling forwarding process from the routing process. The proposal is interested in provisioning quality of service guarantees for planned Wireless Mesh Networks which are being used widely as a broadband wireless access network.**

***Keywords* — Wireless Mesh Network, Traffic Engineering, QoS aware routing.**

1. Introduction

Generally, although rapid traffic growth on some links due to flash events or network outages can cause much demands for bandwidth, at the same time we often have other links in our network that are underutilized or idle. Traffic engineering, as its core, is the art of moving traffic around so that traffic from congested links is moved onto the unused capacity on the other links. So, providing traffic engineering support in multi-hop wireless network has become increasingly important due to the low bandwidth nature of wireless channels.

In wired networks, especially in Multiple Protocol Label Switching (MPLS), decoupling routing and forwarding is one of the key factor to fulfill traffic engineering aspect. As far as our knowledge, there appears to be no prior public work in the area of traffic engineering that focuses on separating routing and forwarding algorithms in multi-hop wireless network. In this paper, we propose a Link Quality-Aware Packet Forwarding Architecture that can change how a packet forwarded without affecting other nodes within the wireless network environment. In other words, routing and forwarding work independently so that the packet can alter its path without invoking routing to re-calculate the path, set it up before sending the traffic and tear it down after fishing the sending. The overhead therefore reduces significantly when the network is high loaded.

In the proposal, we are interested in provisioning QoS guarantees for Wireless Mesh Networks (WMNs) which are being used as access networks. WMN has emerged recently as a promising technology with many important attributes: reliability, adaptability, simplicity but scalability and cost saving. They can be applied to many scenarios such as home networking, community networking, and enterprise networking and so on. A wide range of applications with various required traffic patterns will be run over these networks, for instance, VoIP, VoD and audio-video conferencing that expect low delay bounds and minimal jitter while file sharing requires large bandwidth.

The rest of this paper is organized as follows: Section 2 lists related works and the inspiration leading to our idea. Section 3 presents network model and assumptions. Section 4 depicts Link Quality-Aware Packet Forwarding Architecture for Wireless Mesh Network. Section 5 studies the performance of our proposed scheme using ns2. Section 6 concludes main points of this paper and future works

(*) This research was supported by the MIC under the ITRC support program supervised by the IITA (IITA-2006-(C1090-0602-0002))
(**) Dr. Hong is corresponding author.

2. Related work

Unlike traditional IP network model where forwarding and routing co-operatively work to transmit packets between a pair of source-destination, MPLS architecture is split into two separate component: the forwarding component (called the data plane) and control component (called the control plane). The forwarding component uses a label-forwarding table maintained by a label switch to perform the forwarding of data packets based on labels carried by packets. The control component is responsible for originating and maintaining label-forwarding information (referred to as bindings) among group of interconnected label switches [1]. MPLS node architecture is shown in Figure 1.

Due to the limit in bandwidth of wireless channel, using labels to separate routing and forwarding like MPLS seems not efficient in wireless network because labels will introduce much overhead. In [2], the author tried to apply the concept of "label switching" for Multi-hop Wireless LAN. Accordingly, the network interface card is enhanced to store a label switching table, consisting of an incoming MAC address, an incoming label, an outgoing MAC address and a an outgoing label. The primary goal of "label switching" for Multi-hop Wireless LAN is to speed up switching and therefore improve the end-to-end delay for a packet. However, switching speed is not a big concern of "label switching". The real motivation for us to consider using label is the application it enables. One of them is traffic engineering. In this paper, we use the term "decoupling routing and forwarding" which is not based on "label" to realize traffic engineering in WMNs.

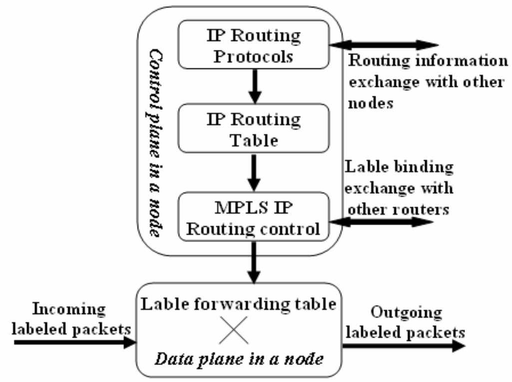


Figure 1. Basic Architecture of an MPLS Node Performing IP Routing.

3. Network Model and Assumption

In this paper, Mesh architecture usually comprises of two components: Mesh Routers (MRs) and Mesh Clients (MCs). The MRs, considered stationary or with very low mobility, are ad hoc-like connected to form network backbone. Some of them operate as Gateways to the Internet (IGW-Internet Gateways). Through the backbone formed by MRs, Mesh Clients, either stationary or mobile, can access the Internet through intermediate MRs before reaching their corresponding IGWs. In WMN, each MR generates and forwards its traffic to the IGW in a chain model. It is clear that MRs closer to the IGW have to forward more traffic than nodes farther away.

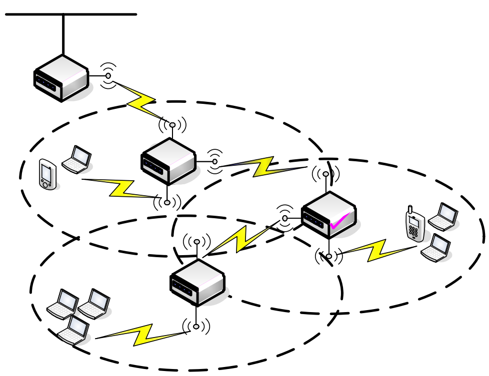


Figure 2. Three-radio MRs in Wireless Mesh Network.

Multi-channel approach using multiple radios is applied at each MR to eliminate potential co-channel interference. Accordingly, non-overlap channel is assign to two MRs which are within the interference range of each other. Because the number of interfaces per node is limited, each node typically used one interface to communicate with multiple of its neighbours. In our paper, we assume that each MR is equipped with three radios: two for communicating in the backbone network i.e. with other peer MRs while third radio is used to explicitly communicate with MCs (Figure 2).

We introduce two definitions about IGW. (i) *Primary IGW* of a node is the default IGW that a MR uses to access the Internet. One node has only one Primary IGW which is assigned by network administrator when it is installed in the network. (ii) *Secondary IGW* of a node is the IGW that the node uses to access the Internet when its Primary IGW gets busy or broken. One MR has a couple of Secondary IGWs which are assigned by the network administrator when it is installed in the network.

The new terms defined above will facilitate routes management and path selection at each MR. One MR can not send its traffic to Secondary IGWs when its routes to default IGW still have available resource.

4. Link Quality-Aware Packet Forwarding Architecture for Wireless Mesh Network

"Link Quality-aware" term was presented in QoS-Aware Routing for Mobile Ad Hoc Networks [3] [4] [5]. In the scheme shown in Figure 3, MAC layer is responsible for measuring link quality or link metrics such as: bandwidth, delay, loss rate, etc. Link metrics then are introduced to IP routing protocol where routing algorithm will take link metrics into account in order to calculate the path for the new incoming flow. Contention-aware Admission Control may be employed at each node to determine whether available resources can meet requirements of the new flow while maintaining bandwidth levels for existing flows [4].

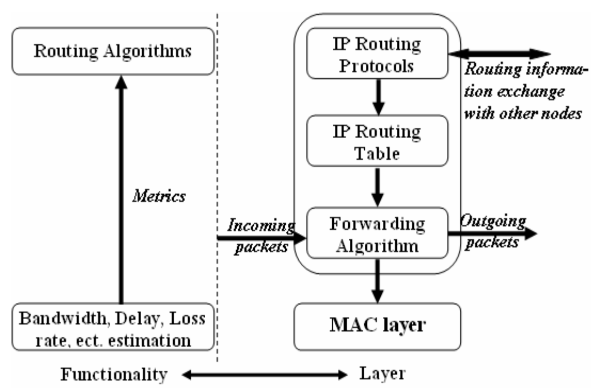


Figure 3. QoS-aware Routing Architectrue.

However, QoS-aware routings usually raise some following issues. Firstly, they are much more sophisticated than those based on Hop-Count. Thus, it can cause many difficulties in finding the optimal routes. Secondly, if the metrics are not measured correctly, the imprecision will impact the whole network. Thirdly, they use much overhead in globally signalling for the new paths. These problems can be solved by separating routing and forwarding. In other words, forwarding will not depend on routing in a sense that if we want to change the traffic's direction to avoid congested link, we don't need invoke routing at each nodes to re-calculate the path and update the routing table. Thus, a locally signalling will replace globally signalling to reduce considerable overhead.

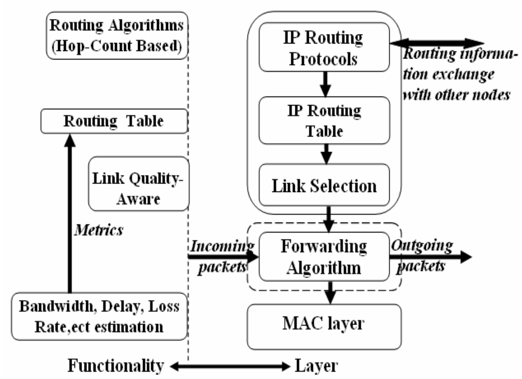
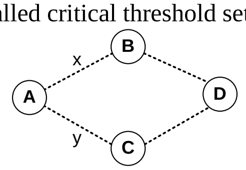


Figure 4. Link Quality-Aware Packet Forwarding Architecture.

The primary key advantage of our proposal is that we keep the routing simple and stable by using Hop-Count based routing. The proposed Forwarding Architecture is shown in Figure 4. The metrics are not taken by routing algorithm like QoS-aware routing. Instead, they are updated in an enhanced routing table. Correspondently, routing table at each node will be added two new entries to store the metric for each of the node's connected links and a flag for indicating the activation status of corresponding route. The Figure 5 illustrates our preceding description. There are two two-hop paths from source A to destination D. Suppose that x and y are two values of link metric measured by node A over link AB and link AC. Node A will put these values in its routing table, next to correspondent entries (Figure 5b). Forwarding now uses new routing table not only looking for next hop but also being aware of outgoing link quality. However, to help forwarding algorithm to select the right next hop, we present Link Selection mechanism which decides if the link to the next hop is good enough for the traffic flows. A flag is added with the value of 0 in case the route to next hop is selected and -1 if the route is deactivation. Deactivation route has two meanings. It is a bad route to forward packets or it is a back up route which is used when the Primary route goes down. Actually, Link Selection is a comparator which evaluates the link metric with a critical value called critical threshold set by Administrator.



(a)

Source	Destination	NextHop	Metric	Activation
A	D	B	x	0
A	D	C	y	-1

(b)

Figure 5. New routing table used in our proposal.

5. Simulation

In this section, we evaluate the performance of our proposed routing protocol in a specific scenario using NS2 extension supporting Multi-channel Multi-Interface for Wireless multi-hop network [6] (proposed in Hyacinth and developed in NS2 2.29).

We choose AOMDV (Ad hoc On-demand Multi-path Distance Vector) due to its simplicity and stability. In our proposal, we don't need to find multiple link-disjoint paths but possible routes from the source to the destination because of two reasons. Firstly, our multi-path routing scheme will send traffic primary on a single path, employing alternate paths only when the primary path is heavily loaded. Secondly, each node equipped multiple radios can send and receive traffic simultaneously over more than one connected links.

The consumed bandwidth is chosen as the metric in our proposal. We use "Hello" Bandwidth Estimation technique to measure bandwidth. Every host have to broadcast information about its current bandwidth in "Hello" messages from its neighbours. The bandwidth consumed information can be piggybacked onto the "Hello" message which is used to maintain local connectivity among nodes [3].

With the support of bandwidth estimation mechanism described above, each MR can detect the congestion risk occurring on its each link. We assume that a link is at congestion risk whenever the available bandwidth of that link is lower than a value of bandwidth, e.g. 10% channel capacity. We called it *critical threshold*. If one of the links of an MR can not handle more traffic, it will refuse to accept more flows over that link while it checks its cache to choose another path for the new traffic. A per-connection granularity is applied at each node to allocate all traffic for one connection to a single path. The threshold scheme is shown in Figure 6.

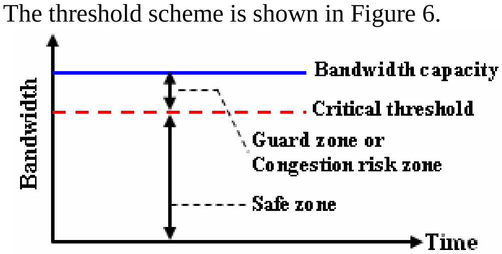
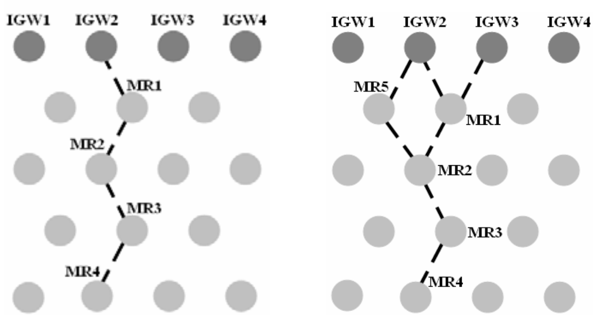


Figure 6. Proposal link selection mechanism based on critical threshold.

The proposal topology is a static wireless mesh network with a number of nodes arranged in the area of 1000x1000 m^2 (Figure 7). Each MR is equipped with three radios; each of them is permitted to operate with multiple non-overlap channels. We select 802.11b standard supporting 11 Mbps per radio. All MR has a fixed transmission range of 250m and interference range of 550 m.

First of all, we study how the traffic is routed from the MR source to IGWs while traffic load gradually increases on a specific path. We consider a four-hop path from MR1 to IGW2. Each MR along the path originates and forwards its traffic to IGW2 in the chain model. We choose UDP packets with 1024-byte payload to stand for real-time applications. Figure 7a and 7b show the path of traffic when load of each node is

160 and 210 packets per second. In the former, MR1, MR2, MR3 and MR4 take the shortest path from itself to IGW2. In the latter, traffic splits at MR1 and at MR2. When the consumed bandwidth over link MR1-IGW2 reaches the critical threshold, MR1 routes the excessive bandwidth over link MR1-IGW3 to avoid congestion. The similar situation happens at MR2 when link MR2-MR1 can not handle more traffic.



(a) load = 160 packets/s (b) load = 210 packets/s

Figure 7. Traffic routed from MRs to their IGWs.

Secondly, we vary the traffic rates to measure throughput and delivery ratio of these MRs by increasing number of flows along with time. We can see that a big improvement in the average throughput and delivery ratio of MR4, MR3, MR2 and MR1 in our proposal (Figure 8) compared to pure AODV and AOMDV which is merely based on Hop Count to find the shortest path. In our design, each of examined MR can reach its maximum throughput due to the capability of predicting congestion risk and sharing load among multiple paths to protect links from overloaded. Consequently, our proposal has a much better delivery ratio compared to AODV and AOMDV (Figure 9). The throughput varies according to MRs' position. The MRs located near the IGW get a higher throughput due to loss rate increase over a longer path. When traffic increases, IGW2 quickly became a performance bottleneck of whole networks below. In congestion situation, the traffic from nearby IGW will choke the longer path length flows.

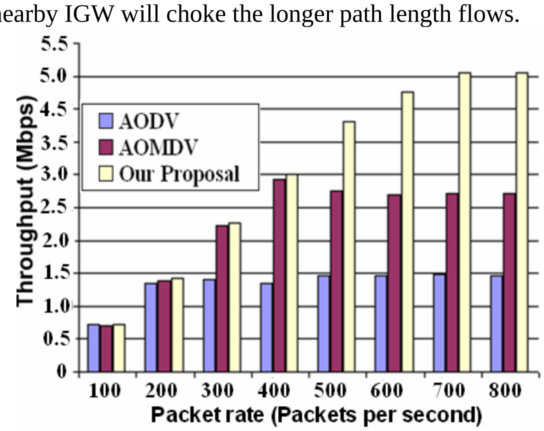


Figure 8. Throughput analysis in comparison with AODV and AOMDV.

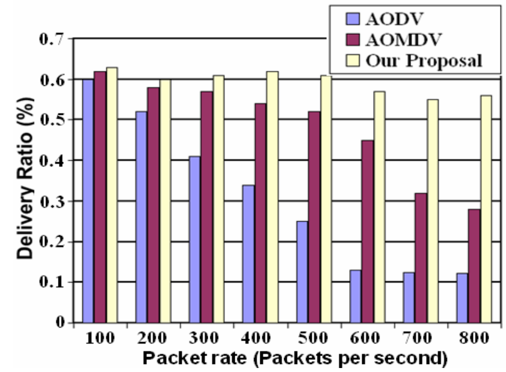


Figure 9. The delivery ratio analysis in comparison with AODV and AOMDV.

6. Conclusion

In this paper, we propose a novel scheme in which routing works independently to forwarding to fulfill the simplicity for routing algorithm while ensure the quality of service for various categories of traffic. In the proposal, routing has run based on Hop-Count while forwarding has taken bandwidth as a metric for conveying the packets. However, we can apply any kind of metric besides bandwidth without affecting the routing algorithm. Our scheme can overcome the big disadvantage of Hop-Count metric. Therefore, it can improve significantly the performance compared to AODV and AOMDV.

REFERENCES

[1] Ivan Pepelnjak, Jim Guichard, "MPLS and VPN architectures", Cisco press 2001

[2] Arup Acharya, Arhan Misra, Sorav Bansal, "A label-switching Packet Forwarding Architecture for Multi-hop Wireless LANs", Proc. of 5th ACM international workshop on Wireless mobile multimedia 2002 , pp. 33-40

[3] Lei Chen, Heinzelman W.B,"QoS-Aware Routing Based on Bandwidth Estimation for Mobile Ad hoc Networks", IEEE Journal on Selected Areas in Communications, Volume 23, Issue 3, March 2005 Page(s):561 - 572 2005

[4] Yaling Yang, Kravets R.,"Contention-Aware Admission Control for Ad Hoc Networks", IEEE Transactions on Mobile Computing, Volume 4, Issue 4, July-Aug. 2005 Page(s):363 – 377

[5] Richard Draves, Jitendra Padhye, and Brian Zill, "Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks", in ACM Mobicom, 2004

[6] NS2 Notebook: Multi-channel Multi-interface Simulation in NS2, http://www.cse.msu.edu/~wangbo1/ns2/nshowto8.html.