Hop-Count Based Congestion-Aware Multi-path Routing in Wireless Mesh Network*

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***Abstract*— In recent years, Wireless Mesh Network (WMN) is a compelling topic to many network researchers due to its low cost in deployment, simplicity in installation and robustness in operation. However, existing routing protocols designed for MANET can not work efficiently in WMN because backbone in WMN formed by Mesh Router has very low mobility and are not put under power and memory constraint. In addition, they just concentrate on finding single path from the source to the destination while the characteristics of robustness of WMN require that every intermediate Mesh Router should establish several paths from itself to its desired destination. In our paper, we design a routing protocol that permits each MR to quickly discover multiple paths based on Hop Count metric to the Internet Gateways. Unfortunately, Hop Count does not take packet loss or bandwidth into account. It results in low throughput of a flow that follows the shortest path. A bandwidth estimation technique has been proposed to apply at each Mesh Router to allow it to predict congestion risk over its connected links and to select high available bandwidth link for forwarding packets. A detailed performance evaluation shows that the throughput increases greatly compared to pure AODV and AOMDV in high-loaded traffic scenario.**

I. Introduction

Wireless Mesh Network (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.

Mesh architecture usually comprises of two components: Mesh Routers (MR) and Mesh Clients. 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) where they act as proxies for admission control, flow reservation, firewall [1]. Through the backbone formed by MRs, Mesh Clients, either stationary or mobile, can access the Internet through intermediate MRs before reaching their corresponding IGWs.

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Due to peculiar characteristics of WMNs' components and applications that run over them, a multi-path routing protocol is really a need to lower congestion risk and to increase reliability compared to their single-path counterparts [2]. However, it is shown that splitting TCP traffic over multiple paths causes degradation of performance due to the fact that TCP reacts to RTT and other network parameters quite sensitively [3]. In addition, while using multi-path relieves "hot-spot" congestion, it also decreases performance elsewhere in the network where more traffic is distributed [4]. More importantly, forwarding traffic over multiple paths will increase significantly jitter which degrades performance of real-time application. Therefore, our multi-path routing scheme will send traffic primary on a single path, employing alternate paths only when the primary path is heavily loaded.

Researchers have proposed many metrics for WMN and applied them in QoS-aware routing. However, QoS-aware routing sometimes introduces a sophisticated and unstable algorithm, a lot of overhead and much complexity for measuring the link QoS metrics as well as for calculating, establishing and tearing down the paths. As far as our knowledge, Hop Count metric still predominates in routing implementations these days due to its simplicity and stability. The main drawback of Hop Count metric is that it doesn't allow choosing highest throughput paths. In this paper, we design a mechanism that can detect the congestion risk over links of each node to support Hop Count metric to overcome its disadvantage.

This paper has several following key contributions: (i) We describe a multi-path Hop-Count based routing protocol that can effectively applied for WMN architecture due to its simplicity, stability and practicability. (ii) We design a mechanism that can support our Hop-Count based routing to predict congestion and avoid it. (iii) Our proposal permits to change how packet is forwarded, without affecting the routing algorithm. In other words, packets will change their routes without invoking routing algorithm to tearing down the old path and establishing the new one so it can save time and overhead. (iv) In simulation part, we show that our proposal can improve network performance in a sense that it can avoid congestion, provide better performance than pure AODV and AOMDV.

The rest of this paper is organized as follows: Section II lists related works and the inspiration leading to our idea. Section III presents network model and assumptions. Section IV depicts the basic multi-path routing protocol based on

AODV with some modifications. Section V introduces bandwidth estimation technique and congestion-aware mechanism that are applied at each node to fulfil traffic engineering. Section VI shows the performance analysis of our proposed scheme using ns2. Section VII concludes main points of this paper.

II. Related Work

Traditional routing protocols like AODV [13], DSR [15], and DSDV [14] select route solely based on the number of hops. Recent work [7] [8] show that a route that minimize the hop count does not guarantee the throughput of a flow. However, Hop Count metric has a big advantage because of its simplicity in computing compared to other metrics described below.

Several metrics are proposed for wireless mesh networks: ETX [7] [8], ETT and WCETT [8], MIC [9]. All of these metrics introduce much overhead in the way they are measured and calculated. For instance, to measure ETX metric, each node sends a number of probe packets and waits for report from its neighbor. ETX is calculated based on the number of packets successfully received by its neighbor in both directions. Nevertheless, they don't consider the bandwidth of the wireless links which can ensure performance for real-time application.

Literatures [11] [12] present bandwidth as a QoS metric in accompany with admission control to assure that each flow will receive enough bandwidth for the traffic requirement during its lifetime. However, all of the proposals are designed to efficiently adapt to characteristics of high node mobility and lack of fixed infrastructure of ad hoc network while the nature of backbone nodes in WMN is stationary. In addition, QoS-aware routing and admission control required much complexity and overhead in algorithms, path calculation, setting it up and tearing it down.

Our proposal is inspired by existing studies on Hop-Count based routing and bandwidth estimation techniques. In our study, we design a mechanism to permit MR to evaluate their consumed bandwidth to support Hop-Count based routing while being aware of congestion risk. Our proposal therefore can improve the quality of service of real-time application as well as fulfilling traffic engineering aspect.

III. Network Models and Assumptions

We assume that each MR is equipped with multiple radios and there are multiple channels available in the network. Due to broadcasting nature of wireless medium, links using the same channel will interfere with each other. So we further assume that there is a static channel assignment to avoid channel interference in the network [10]. Non-overlapped channel is assigned to two mesh routers which are within the interference range of each other. Otherwise, channels can be reused for the links if they do not interfere with each other. After static channel assignment, routers in the network can send and receive data simultaneously.

We would like to 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.

IV. Multipath Routing Protocol in WMN

WiMesh-MRP (Multi-path Routing Protocol in WMN) in our proposal is based on AOMDV [16] designed primarily for highly dynamic ad hoc networks. However, the main design of AOMDV has been modified to adapt to the stationary nature of nodes in a Wireless Mesh Network.

In the proposal, we do not need to find multiple link-disjoint paths due to 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 goal of WiMesh-MRP is to find all possible routes from source to the destination. For instance, in the Figure 1, there are 2 link-disjoint paths from source A to destination D: A-C-D-E-G and A-B-D-F-G but there are 4 possible paths as follows A-C-D-E-G, A-B-F-G, A-B-D-E-G and A-C-D-F-G.

A. Route Discovery Phase

Whenever an MR needs a route to an IGW, it initiates a route discovery process by disseminating a route request (RREQ) to all its neighbors. Every MR hearing the RREQ re-broadcasts it until it reaches the destination or a node knowing how to reach the destination. The RREQ originator inserts its sequence number in the RREQ, allowing MRs to avoid relaying the same RREQ twice.

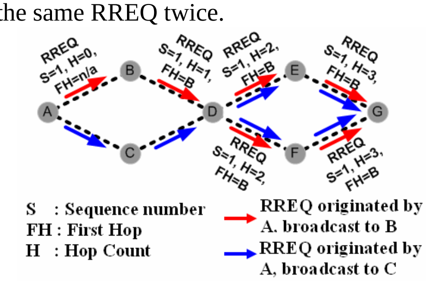


Figure 1. Broadcasting RREQs in AOMDV

Unlike AOMDV, duplicate copies of RREQ are not immediately discarded in WiMesh-MRP. Each copy is ascertained by examining to see if it comes from different *first hops* neighbors. Each RREQ contains a new field called *First Hop* (FH) to indicate the first hop (neighbor of source) taken by it. Also, each MR maintains a *nexthop_list* in its routing table for each RREQ to keep track of list of neighbors of the source MR through which a copy of RREQ has been received.

In the Figure 1, MR A wants to establish multiple paths for itself to MR G. It broadcasts two copies of RREQ to MR B and MR C (over two different channels). In the first broadcast, field LH in RREQ is marked N/A (Not Available). MR B and C record the information from the incoming RREQ and re-broadcast them after updating the hop count field in the packet. The RREQs continued to be conveyed toward to MR G. Finally, MR G receives four RREQs, two from E and two from F.

An MR hearing the RREQ uses the information in the RREQ to set up a route back to the originator (called reverse route). If the receiving MR knows how to reach the destination, it sends a route reply (RREP). The RREP travels on the reverse route to the source node. The number of RREP the destination sends back to the source is equal to the number of RREQ it accepts. Figure 2 shows the routing table of MR A after receiving four RREPs from MR G.

Destination	G
Sequence Number	1
Advertised HopCount	4
Route_List (HopCount, NextHop, LastHop)	4,B,E 4,B,F 4,C,E 4,C,F

Figure 2. Routing table at node G after receive four RREQs.

B. Path Selection

Among multiple paths established in path discovery phase, a source node should decide which one is the best for its traffic requirement. In our paper, we prioritize the path selection in following order:

If there are multiple paths leading to source's primary IGW. (i) Take the path with the lowest hop count (the number of router in the path). (ii) If there is still a tie, take the path at random.

If there is no path to source's primary IGW but a several paths to secondary IGWs. (i) Take the path with the lowest hop count. (ii) If there is still a tie, take the path at random.

V. CONGESTION-AWARE MECHANISM BASED ON BANDWIDTH ESTIMATION TECHNIQUE

A. Bandwidth estimation techniques

To offer awareness of congestion risk, the available bandwidth on a specific link should be known. There are two existing method to measure bandwidth. One is for host to keep track the channel and calculate the available bandwidth based on the ratio of free and busy times [12]. The other is for every host to broadcast information about its current bandwidth in "Hello" messages from its neighbors [11]. In our paper, the bandwidth consumed information can be piggybacked onto the "Hello" message which is used to maintain local connectivity among nodes.

As defined in IEEE 802.11 MAC, hosts are allowed to access the wireless channel when the media is free. The media can be free if no hosts are transmitting packets within the interference range. Normally, the interference range is more than twice the transmission range. With the frequency reuse pattern discussed in Network model section, we can simplify the bandwidth calculation problem to determine the consumed bandwidth within the two-hop neighborhood range. Therefore, each host can approximate its available bandwidth information based on information from hosts within two-hops. In the Figure 3, we consider three pairs of nodes A-A', B-B' and C-C' using channel 1 to communicate with each other. Node A and B are forwarding packets to node A' and B' respectively. Because node C (using channel 1 to talk with C') is in interference range of both node A and node B, consumed bandwidth at node C will conclude consumed bandwidth of node A and node B. For instance, flow 1 from A to A' and flow 2 from B to B' require 800 Kbps and 700 Kbps channel bandwidth, respectively. Two "Hello" messages containing consumed bandwidth on channel 1 from A and B are sent to node C. C receives two messages, calculating its available bandwidth (around 500 Kbps on the supposition that the wireless channel is 2Mbps).

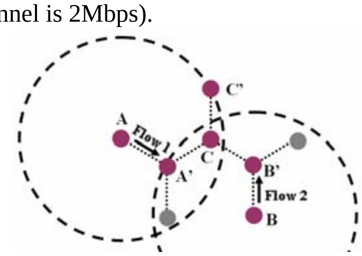


Figure 3. Illustrated scenario for bandwisth estimation

Each host determines its consumed bandwidth by monitoring the packets it feeds into the network. If, every second, the application generates R packets per second with average packet size L bits and H bits header, the corresponding channel bandwidth requirement, W, can be expressed as $W = R \times T_{data} \times B_{channel}$, where

$$T_{data} = T_{RTS} + T_{CTS} + \frac{L+H}{B_{channel}} + T_{ACK} + 3T_{SIFS} + T_{DIFS}$$ and $B_{channel}$ is the capacity of the channel.

B. Congestion-aware mechanism

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.

Now, we consider the scenario to clarify the mechanism discussed above. In the Figure 4 (a), four nodes A, B, C, D are a part of a WMN. Node A uses the path A-B-D to send traffic to its Primary IGW. Suppose that the existing traffic on link BD is nearly consumed 90% capacity of that link. If we don't set a critical threshold, a new flow must be accepted by node

B. The bandwidth consumed at that time is higher than critical threshold and nearly hit the bandwidth capacity of that link. It means that congestion will occur on link BD if more new traffic is allowed by node B. In the Figure 4(b), the topology is the same as Figure 4(a). The difference in situation is that node B forward the new flow on the link BC to keep the bandwidth on link BD unchanged, lower than critical threshold. The threshold scheme is shown in Figure 4(c).

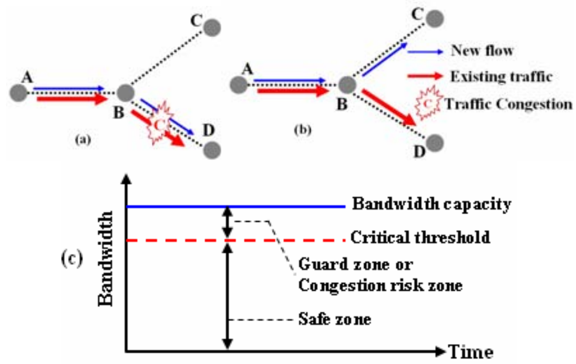
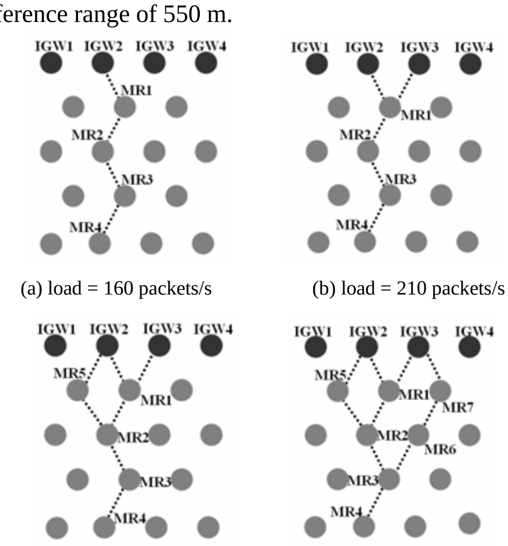


Figure 4. Illustrated scenario for bandwidth sharing

VI. SIMULATION

In this section, we evaluate the performance of our proposed routing protocol using Multi-channel Multi-Interface for Wireless Network Simulation in NS2 (proposed in Hyacinth and deployed in NS2 2.29) with some modification to support congestion-aware mechanism described in section V. We consider the static wireless mesh network with a number of nodes arranged in the area of 1000x1000 m^2 (Figure 6). 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.



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

(a) load = 310 packets/s (b) load = 380 packets/s

Figure 5. Traffic routed from MRs to their Primary Gateway with congestion-aware mechanism

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 the path MR4-MR3-MR2-MR1-IGW2 where each MR originates and forwards the traffic to IGW2 (suppose that all of four MRs consider IGW2 as their Primary gateway) in the chain model. We choose UDP packets with 1024-byte payload to stand for real-time applications. When the traffic load is 160 packets per second, it follows the route MR4-MR3-MR2-MR1-IGW2 as shown in Figure 5(a). It is the shortest path from MR4, MR3, MR2 and MR1 to theirs Primary Gateway IGW2. Figure 5(b) shows the path of traffic when load of each node is 210 packets per second. At MR1, the traffic is sharing between two links: MR1-IGW2 and MR1-IGW3. The reason is that when the rate is 180 packets per second, the traffic over link MR1-IGW2 reach the critical threshold. So the MR1 will forwards a part of its incoming flow to link MR1-IGW3, over which the traffic available is enough for the excessive traffic. Figure 5(c) and 5(d) show the path of traffic when loads are 310 and 380 packets per second, respectively. In the former, the traffic is split at MR2 when the link MR2-MR1 hits its critical threshold of congestion risk. In the latter, the link MR3-MR2 is at risk of congestion due to the traffic from MR4 and MR3 continue increasing. MR3 takes an alternate path MR3-MR6-MR7-IGW3 for the traffic to avoid the congestion on link MR3-MR2.

Through the simulation, we found that one serious problem may happen in our proposal. In Figure 5(d), if the traffic which is split at MR3 follows the path MR3-MR6-MR1-IGW3, the link MR1-IGW2 will be overloaded unexpectedly. To avoid such that situation, we propose a small mechanism to permit each node to notify its downstream nodes about congestion happening on upstream nodes. In the Figure 6, node C send CRN (Congestion Risk Notification) message to its downstream nodes A and B to prevent them from sending more traffic to high loaded link CD and CE leading to IGW. A and B after receiving notification from C will set a timer indicated in CRN message. If timeout happens before receiving another CRN message, node A and B will consider that they can continue sending traffic to node C. Otherwise, both node A and B will reset timer and choose the other paths for their traffic.

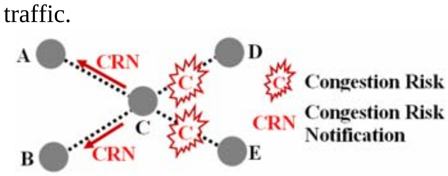


Figure 6. Congestion risk notifications are sent toward downstream nodes

Next, we vary the traffic rates to measure throughput of these MRs by increasing number of flows along with time. We can see that a big improvement in the throughput of MR4, MR3, MR2 and MR1 in our proposal (Figure 7) compared to pure AODV which is merely based on Hop Count to find the shortest path (Figure 8). 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. 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. With pure AODV, the MR4, MR3, MR2 and MR1 use the overlap shortest path MR4-MR3-MR2-MR1 to forward their traffic to IGW2. However, when traffic increases, IGW2 quickly could be a performance bottleneck of whole networks below. In congestion situation, the traffic from nearby IGW will choke the longer path length flows.

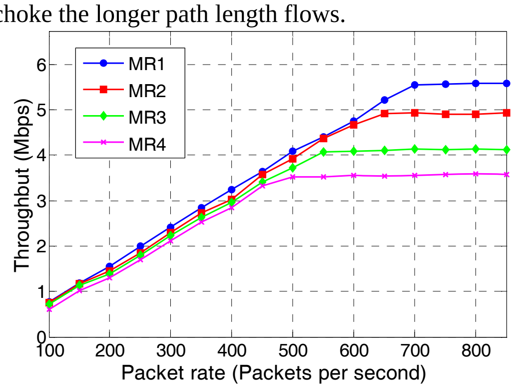


Figure 7. Throughput of flows with our proposal.

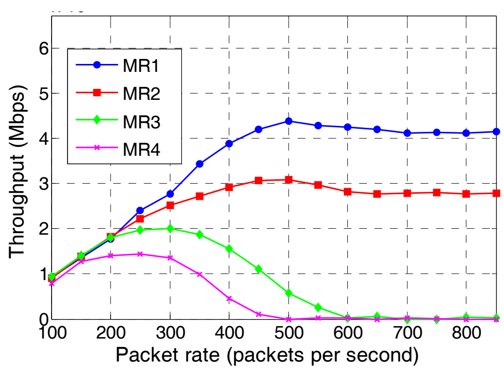


Figure 8. Throughput of flows with pure AODV

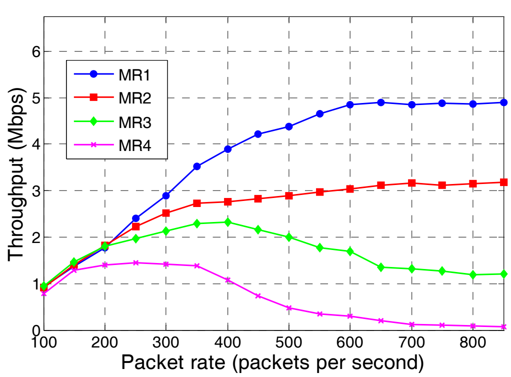


Figure 9. Throughput of flows with AOMDV

As for AOMDV, the throughput of the nodes which are far from IGW also degrades greatly because these nodes just forward packet hop-by-hop and are not aware of congestion when traffic is heavily loaded. Additionally, finding multiple disjoint paths in AOMDV limits the capability of multiple radios multiple channels deployment. In the Figure 9, we can see that AOMDV give a much better performance than pure AODV but still lower performance with our proposal 30%.

VII. CONCLUSION

In this paper, we propose a reactive Hop-Count based multi-path routing protocol but can be aware of congestion. Our proposed routing protocol achieves several outstanding properties of Hop metric-based routing algorithm: simplicity in routing algorithm, stability and backward compatibility in operation and practicability in implementation. Additionally, with support of congestion-aware mechanism, nodes can choose links which have enough available bandwidth for incoming flow's requirement. Therefore, our proposal can overcome the big drawback of Hop Count metric. Our protocol helps in dramatically increasing the performance up to 200% compared to pure AODV and 130% to AOMDV employed in WMN. Our work also reduces a great amount of overhead and complexity of algorithm against existing QoS routing for WMN.

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