Multi-path Routing Protocol Using Cross-Layer Congestion-Awareness in Wireless Mesh Network*

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ABSTRACT

Recently, the WMNs (Wireless Mesh Network) have increased their popularity and kept the interest of the most important research groups all over the world due to their self-configuring, self-healing capabilities, as well as their low equipment and deployment cost. Most of research work carried out in WMN is prone to be simple, practical to build up confidence in commercial implementation of these networks. In this paper, we present a multi-path routing protocol using Hop-Count metric that can be aware of congestion by collecting information from MAC layer. The primary advantage of our paper is to provide a simple and stable multi-path routing algorithm that can provide better than best-effort to real-time applications in wireless environment but need much less overhead compared to QoS-aware routing with two kinds of metrics: bandwidth and WCETT (Weighted Cumulative Expected Transmission Time).

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – Wireless Communication

General Terms

Algorithms, Design.

Keywords

Wireless Mesh Network, Multi-path routing, Congestion Avoidance, Traffic Engineering

1. INTRODUCTION

WMN has emerged recently as a promising technology due to their low cost, and self-configuring and rapid deployment capacities. Mesh architecture is usually comprised 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 Internet (IGW-Internet Gateways) as well as proxies for admission control, flow reservation [1]. Through the backbone formed by MRs, Mesh Clients, either stationary or mobile, can access the Internet through intermediate MRs before reaching Gateways.

Depending upon characteristics of the components of WMNs and applications that run over them, a multi-path routing protocol is really a need to lower packet loss rate while to increase reliability and overall network performance compared to their single-path counterparts. One of the most important factors deeply impacting to routing protocol performance is choosing a right routing metric for the specific kind of network. Researchers have proposed many metrics for WMNs such as ETX [2] [3] [4], ETT and WCETT [3], MIC [5]. However, QoS-aware routing introduces a sophisticated routing algorithm and much overhead to set up and reserve resources before sending the traffic. In reality, Hop-Count still predominates in routing implementations today due to its simplicity and stability. The main drawback of Hop-Count is that it doesn't permit to choose highest throughput paths available. In this paper, we design a mechanism that can detect the congestion risk on connected links of MRs using information from MAC layer to support Hop-Count to be aware of congestion.

Our paper has several key contributions as follows: (i) We propose a simple and stable multi-path routing protocol that can effectively applied for WMN architecture. (ii) A bandwidth estimation technique applied at each node to predict congestion risk and avoid it. (iii) Our proposal permits to change packet's path without affecting the routing algorithm. In other words, packets can alter their routes without re-establishing the routing table or new routing services can be added without a change to the forwarding paradigm. So it can save time and overhead. (iv) In simulation part, we show that the proposal can improve network performance in sense that it can avoid congestion, provide better than best effort and reduce overhead.

The rest of this paper is organized as follows: Section 2 lists related works and the inspiration leading to our idea.

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

Section 3 presents network model and assumptions. Section 4 depicts the enhanced multi-path routing protocol based on DSR. Section 5 introduces bandwidth estimation technique and congestion-aware mechanism that are applied at each node to fulfill congestion prediction. Section 6 studies the performance of our proposed scheme using ns2. Section 7 concludes main points of this paper and future works.

2. RELATED WORK

Traditional routing protocols like AODV [14], DSR [13], and DSDV [12] decide route solely based on the number of hops. Recent work [3] shows that a route that minimizes the Hop-Count does not guarantee the throughput of a flow. However, Hop-Count has a big advantage due to its simplicity in computing compared to other metrics described below.

Several metrics are proposed for WMNs: ETX [2] [3], ETT and WCETT [4] [5], MIC [5]. 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 the 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 such as VoIP, VoD and some of them don't have property of isotonicity which can ensure loop-free [5].

Literatures [10] [11] 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 routing and admission control required much overhead in 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 MRs to evaluate its residual bandwidth to support Hop-Count-based routing in being aware congestion risk. Our proposal therefore can improve the quality of service of real-time application as well as fulfilling traffic engineering aspect.

3. NETWORK MODEL & ASSUMPTIONS

We assume that each mesh router 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 a static channel assignment is deployed to avoid channel interference in the network [8] [9]. 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. They don't need to synchronize with other nodes for the channel and also don't need to modify MAC layer protocol.

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

4. MULTI-PATH SOURCE ROUTING

It is shown that splitting TCP traffic over multiple paths can meet some issues. Firstly, TCP performance can be degraded seriously due to the fact that TCP reacts to RTT and other network parameters quite sensitively [6]. Secondly, while using multi-path relieves "hot-spot" congestion, it also decreases performance elsewhere in the network where more traffic is distributed [7]. Thirdly, 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.

4.1 Route Discovery Phase

The proposed routing protocol builds routes on demand in route discovery phase. A source initiates route discovery by broadcasting ROUTE REQUEST (RREQ) message in the network to seek a route to the destination. Each request message contains the sequence of hops it passed through in message header. When IGW destination receives RREQ from intermediate MRs, it sends back a ROUTE REPLY (RREP) message along the reverse route to the source. If an intermediate node has a route to the destination in its cache, then it can append the route to the route record in Path field of RREP and send it back to the source containing this route. This can help limit flooding of the RREQ in the network. In multi-path routing, many copies of disseminated requested messages arrive at the destination via different routes. In our proposal, the queries that are replied to are those that carry non-identical source routes. Our aim is to establish a mesh of routes that contains all possible routes from a specific MR to IGWs.

4.2 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 propose the tiebreakers among paths, in order:

If there are multiple paths leading to destination'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 destination'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

4.3 Route Maintenance

A link failure may cause to drop packets on that link. So, when forwarding a packet using a source route, each node transmitting the packet is responsible for confirming that packet has been received by the next hop along the source route. The node will retransmit the packet if no confirmation is received. When the number of retransmission times reaches the designed limit value, this node returns ROUTE ERROR (RERR) message to the original sender of the packet, identifying the link over which the packet could not forwarded. When each intermediate MR along the source route receives the RERR message, it will remove all the routes containing the broken link.

5. CONGESTION-AWARE MECHANISM BASED ON BANDWIDTH ESTIMATION

To offer bandwidth-guaranteed QoS, the available end-to-end bandwidth along a route from the source to the destination must be known. The end-to-end throughput is a concave parameter [10], which is determined by the bottleneck bandwidth of the intermediate hosts in the route. Therefore, estimating the end-to-end throughput can be simplified into finding the minimal residual bandwidth available among the hosts in that route. However, how to calculate the residual bandwidth using the IEEE 802.11 MAC is still a challenging problem because the bandwidth is shared among neighboring hosts and an individual host has no knowledge about other neighboring hosts' traffic status.

5.1 Bandwidth Estimation Technique

In our proposal, each MR is able to estimate the available bandwidth on the links from itself to neighbor MRs. To do that, intuitively, each host can probe the channel to track the traffic state and calculate how much free bandwidth remains in every second. The IEEE 802.11 MAC utilizes both a physical carrier sense and a virtual carrier sense [via the network allocation vector (NAV)] [10] to determine the free and busy times. The MAC detects that the channel is free when the following three requirements are met [10] [11]: (i) the node is NOT transmitting or receiving a packet. (ii) the node does NOT receive or an RTS or CTS message from another node, which reserves the channel for a period of time specified in the message. (iii) the node senses a busy carrier with signal strength larger than a certain threshold, called the Carrier-sensing Threshold, but the node cannot interpret the contents of the message.

Base on the above criteria, a node can estimate the consumed bandwidth using a weighted moving average as follows:

$$B_{local}^{new} = \alpha B_{local}^{old} + (1-\alpha)(T_{idle} / T_p) B_{channel}$$

where T_{idle} is the amount of idle channel time during period of time T_p . B_{local} is the local available bandwidth while $B_{channel}$ is channel capacity and $\alpha \in [0,1]$ is a tunable parameter, $\alpha = 0.3$.

Whenever an MR receives a request for a new flow with a specific traffic pattern requirement, it checks its available bandwidth to accept or refuse the request. To quantify the bandwidth that a new flow will consume, we have to determine the number of packets the flow will feed into the network. If, every second, the application generates R packets with average packet size L and H bits header, the corresponding channel bandwidth requirement, W, can be expressed as

$W = R \times T_{data} \times B_{channel}$, where

$$T_{data} = T_{RTS} + T_{CTS} + \frac{L+H}{B_{channel}} + T_{ACK} + 3T_{SIFS} + T_{DIFS}$$

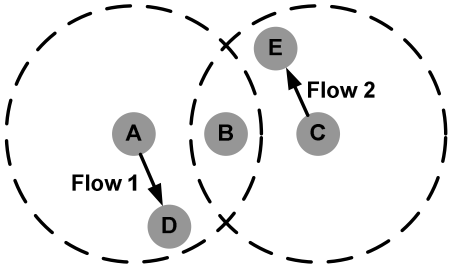


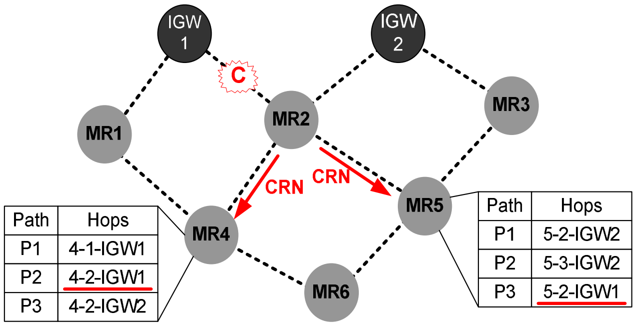
Figure 1: Available bandwidth at node B is affected by node A and node C.

For instance, in Figure 1, flow 1 from A to D and flow 2 from C to E require 600 Kbps and 800 Kbps channel bandwidth, respectively. Because node B is in coverage of nodes A and node C, the available bandwidth at node B is around 600 Kbps on the supposition that the wireless channel is 2Mbps.

5.2 Congestion-Aware Mechanism

With the support of bandwidth estimation mechanism described above, each MR can detect the congestion risk occurring on each its connected link. We assume that a link is at congestion risk whenever the available bandwidth of that link is lower than 10% channel bandwidth. We call it critical threshold.

If one MR detects that one of its link is in congestion risk, it will periodically send Congestion Risk Notification to downstream neighbor nodes. Neighbor nodes after receiving Notification message for a specific link will deactivate the routes in its routing table which contain that link. Concurrently, it sets a timer for the marked routes. If the timeout event happens before receiving another CRN for that link, it will activate these marked routes. Otherwise, it will reset the timer. We consider a scenario in Figure 2 to clarify the mechanism discussed above. If available bandwidth on link MR2-GW1 reached the critical threshold, MR2 will send CRNs to node MR4 and MR5. Receiving CRN from MR2, MR4 will inactivate route 4-2-GW1 and set the timer. Similarly, MR5 marked route 5-2-GW1. MR4 and MR5 have to use an alternate route to forward their packets to IGWs.



Path	Hops
P1	4-1-IGW1
P2	4-2-IGW1
P3	4-2-IGW2

Path	Hops
P1	5-2-IGW2
P2	5-3-IGW2
P3	5-2-IGW1

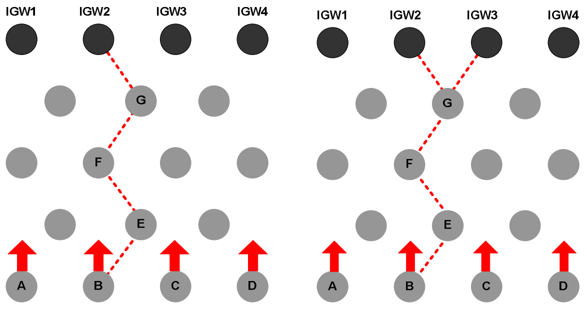
Figure 2: An illustrated scenario for congestion-aware mechanism

To accomplish preceding mechanism, each node has permission to modify the source route of the packet. In pure DSR, source route is kept unchanged in the packet header from the source to the destination. In our proposal, the intermediate node can change the path of the flow to avoid congestion. The flow will take another path from the intermediate node according to its experience of network current status

6. 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 for NS2 2.29) with some modification to support congestion-aware mechanism described in section 5. We consider the static wireless mesh network with a number of nodes arranged in the area of 1000x1000 m2 as Figure 3. Each MR is equipped with three radios; each of them is permitted to operate with multiple non-overlap channels. All MRs have a fixed transmission range of 250m and interference range of 500 m.

Firstly, we study how the traffic is routed from the source MR to its IGWs to avoid congestion while traffic load gradually increases on a specific path. We consider the path B-E-F-G-IGW2 where each MR originates and forwards the traffic to IGW2 in a chain model. We choose UDP packets with 1024-byte payload to stand for time-sensitive applications. When the traffic load of each node is 170 packets per second, all nodes along the path use the overlap routes from B to IGW2 for their traffic as shown in Figure 3a. They are the shortest routes from B, E, F and G to IGW2. Figure 3b shows the paths of traffic when the rate is 230 packets per second. At G, the traffic is sharing between two links: G-IGW2 and G-IGW3. The reason is that node G estimates the available bandwidth and knows that link G-IGW2 can not handle the traffic from all downstream nodes at rate of 180 packets per second. So the G sends CRN to F to inform the congestion risk of link G-IGW2. F then deactivates all the routes containing link G-IGW2. It therefore forwards all new incoming flows over path F-G-IGW3.



(a) load = 170 packets/s (b) load = 230 packets/s

Figure 3: Traffic routed from MRs to their Primary Gateway with congestion-aware mechanism.

Next, we vary the traffic rates to measure average throughput and average packet delivery ratio of the entire network by increasing number sending nodes and number of flows along with time. The results are shown in Figure 4 and Figure 5. We can see that a big improvement in the throughput and delivery ratio of our proposed routing in comparison with pure DSR which is merely based on Hop-Count to find the shortest path to the destination. In our proposal, each of examined MR can reach its maximum throughput because one MR can measure the congestion risk and avoid it by using an alternate path for the coming new flows. With pure DSR, the MRs use the overlap shortest paths to forward their traffic to the IGWs. However, when traffic increases, IGWs quickly could be the performance bottlenecks of whole networks. So, the traffic from nearby IGW will choke the longer path length flows. Consequently, our proposal has a much better delivery ratio compared to pure DSR. As for QoS-aware routing using WCETT, the throughput is little higher than our proposal. The reason is WCETT metric perform well in WMNs compared to bandwidth metric. However, QoS routing using WCETT experiences a complicated routing algorithm and much overhead.

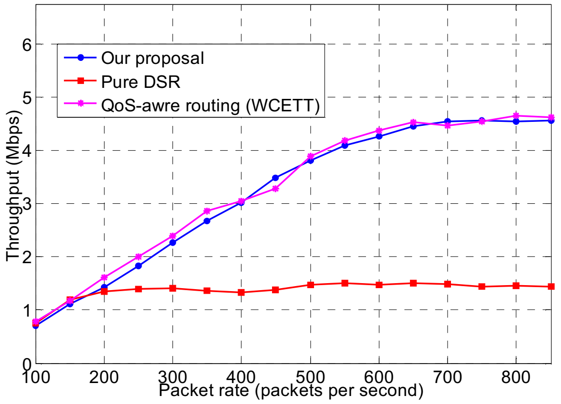


Figure 5: Average delivery ratio of flows among our proposal and DSR-based routing protocols.

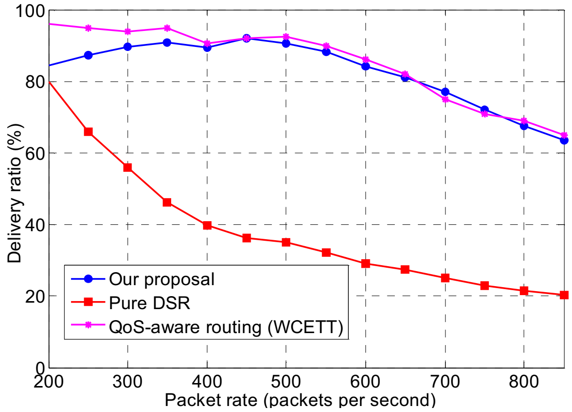


Figure 4: Average throughput of flows among our proposal and DSR-based routing protocols.

Finally, we measure the control overhead for a flow of traffic among our proposal and traditional QoS-aware routing with various kinds of metrics. The total number of source is 14. In Figure 6, we can see that our proposal introduces much less routing overhead than others. It can be explained that in high loaded scenario the congestion will corrupt the on-going flow. With QoS-aware routing protocols, the source and destination nodes then exchange Path Setup message to re-establish the path for corrupted flow. Path Teardown message has been used to tear down the path and release the reservation after source completes its sending. Accordingly, signaling messages will be flooded over *the entire network*. In our proposal, the congestion risk on specific link is predicted by connected nodes. The corresponding node then chooses another path to avoid the congestion. The problem is solved *locally* and therefore introduces much less overhead compared to QoS-aware routing, especially in a large scale network. Using WCETT metric suffers higher overhead than bandwidth metrics due to the method of measurement. However, WCETT works better than bandwidth in the sense of reliability.

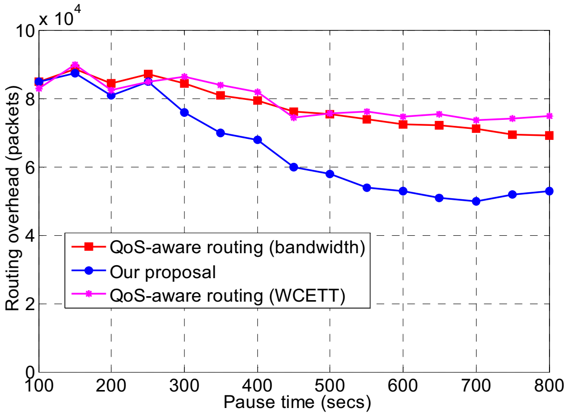


Figure 6: Overhead analysis in comparison with QoS-aware Routing using Bandwidth and WCETT as routing metrics

7. CONCLUSION

In the paper, we propose a reactive multi-path routing protocol-based Hop-Count but can be aware of congestion by collecting information from MAC layer. Therefore, our proposed routing protocol has several outstanding properties of Hop metric-based routing algorithm: simplicity in routing algorithm, stability and backward compatibility in operation (loop-free) and ease and practicability in implementation. However, our proposal can overcome the big drawback of Hop-Count metric. With cross-layer congestion-aware mechanism, node can choose links which have enough available bandwidth for incoming flow's requirement. In addition, our proposal can reduce much overhead compared to traditional QoS-aware routing

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