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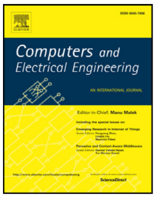

A cross-layer framework for joint routing and rate adaptation in infrastructure Wireless Mesh Networks[☆]

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ABSTRACT

In this paper, we propose a cross-layer framework for joint routing and rate adaptation in multi-rate, Multi-Channel, Multi-Radio (MCMR) infrastructure Wireless Mesh Networks (WMNs). These networks use MCMR capabilities of mesh routers to achieve high performance. However, the MCMR nodes introduce interference in the multi-hop mesh networks and can degrade QoS. Thus, the design of routing metrics to improve the QoS has become an important research issue. Furthermore, as the routing metric and rate adaptation decisions are closely related, the joint approach is needed to improve the performance of the network. Towards this, we analytically derive our routing metric using IEEE 802.11 Distributed Coordination Function (DCF) basic access mechanism. Using this model, we propose Passive Interference and Delay Aware (P-IDA) routing metric which estimates the delay and interference by exploiting cross-layer information. We extend the work by performing joint routing and rate adaptation. The simulation results using NS2 reveal that proposed framework improves throughput and delay compared to existing approaches with reduced routing overhead.

1. Introduction

Wireless Mesh Networks (WMNs) [1] are emerging as a popular technology in the field of multi-hop wireless networks in recent years. These networks are becoming more popular as backbone network to provide ubiquitous internet access and broadband wireless coverage of large areas with minimal upfront investments. WMNs are composed of gateways, mesh routers and mesh clients. Mesh routers generally have the minimum mobility and are employed to form infrastructure/backbone mesh network. These routers act as an access point for mesh clients or forward packets from other routers. The gateways allow backbone WMNs to connect to other types of networks like the internet. Recently, many real-time applications like Voice over IP, online gaming and video streaming are becoming popular in WMNs. These applications depend on adequate QoS support with strict delay requirements. Thus, providing QoS for these applications has become an important research issue [2].

With the reduction in 802.11 hardware costs, mesh routers in WMNs are equipped with single or more radios that enhance the network capability and improve QoS. However, the QoS degrades significantly as the number of nodes or hops increases. Thus, there is the need for routing protocols together with routing metrics to guarantee the QoS. The traditional

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hop-count metric is unsuitable in these networks as wireless link quality varies over a time in terms of delay, loss ratios and link capacity. As mesh routers in these networks forward heavy traffic from mesh client to internet gateways, routers spend a considerable amount of time in binary exponential backoff process. This increases the effective packet delay at the network layer. Thus, there is a need to effectively measure the packet transmission delay, including retransmissions, contention delay and queuing delay. Apart from delay, estimating the inter-flow and intra-flow interference has become an important issue with the increase in the number of radio interfaces. Hence, there is a need for better routing metric that takes into account delay, link capacity and interference to estimate the link quality accurately using cross-layer mechanism.

In addition to MCMR routing, rate adaptation has become an important issue with each node capable of operating at multiple transmission rates depending on 802.11 standards. Many rate adaptation techniques are proposed in the literature. These techniques evaluate current channel conditions and adapt the transmission rate at MAC layer. However, the rate adaptation and routing metrics are strongly related as the link quality estimated by routing metrics is based on the chosen transmission rate. Thus, there is a need for a joint approach to routing metrics and rate adaptation which can improve the QoS. Towards this, to the best of our knowledge, only three works on a joint approach to routing and rate adaptation are reported in the literature [3–5]. However, these approaches are based on single-radio routing metrics and lack analytical model in the design. The contributions of this paper are threefold.

- We analytically derive a delay component of our routing metric by considering transmission and contention delays using IEEE 802.11 DCF model [6].
- Design and implement a new routing metric called Passive Interference and Delay Aware (P-IDA) by estimating the link quality using the above model by accessing PHY, MAC and Network layer parameters.
- Carry out the joint routing and rate adaptation at the MAC layer by using the statistics provided by the routing metric.

The outline of the paper is as follows. In Section 2, we discuss literature review on routing metrics, rate adaptation and joint approaches separately. In Section 3, we discuss about the 802.11 DCF model and proposed routing metric and rate adaptation mechanism based on this model. The Sections 4 and 5 present the simulation environment and evaluation of results respectively. The Section 6 gives the conclusion and future work.

2. Related work

In this section, we discuss the work reported in the literature about routing metrics, rate adaptation and three joint approaches separately.

2.1. Routing metrics

Several routing metrics are proposed in the literature. Here, we review important metrics which are related to our work. Most of the routing metrics proposed in the literature are based on the Expected Transmission Count (ETX) metric as discussed in [7]. The ETX [8] is the first QoS-aware routing metric which is deployed in the WMNs testbed. ETX estimates the total number of packet transmissions required to send the packet to the destination through a wireless link successfully. It is measured by multiplying the forward delivery ratio d_f and reverse delivery ratio d_r of a link. d_f is the measured probability that the packet is successfully received at destination node and d_r is the probability that acknowledgment of the packet is successfully received. The authors demonstrate through testbed results that ETX computes high-throughput routes than the hop count based routing. The problem with ETX is that it does not consider the differences in multiple transmission rates which are very important in multi-rate mesh networks. Furthermore, metric does not explicitly compute the inter-flow interference experienced by the links. Expected Transmission Time (ETT) is proposed in [9] to incorporate the limitations of ETX. The metric estimates the delay of packet at a transmission rate of each individual link. ETT estimates the link quality using packet losses, packet size and available transmission rate of each individual link. The cost of each path is estimated by summing up the ETT values of each link. However, ETT inherits the drawbacks of ETX as it does not consider load and interference.

Another routing metric called Channel utilization and Contention Window (C2WB) is proposed in [10]. The metric is derived using 802.11 MAC delay model but lacks many details. The metric computes the link service time using three QoS parameters, namely transmission time, backoff time and defer time. Using these parameters, the authors estimate the link quality using channel utilization, average contention window and ETT. The metric considers logical interference implicitly using channel contention and balances the load. However, it does not consider interference explicitly and available capacity computation of ETT is static. Another routing metric QUIT which estimates the link quality parameters, namely link quality, channel utilization, interference and traffic load is proposed in [11]. The metric is derived using non-utilized outage capacity analysis, but metric is basically designed for single-radio network.

All the above metrics are proposed for single-radio wireless networks. With an increased demand for multi-radio mesh networks, design of interference-aware routing metrics has become an important research issue. The most popular and the first routing metric proposed for multi-radio networks is the Weighted Cumulative Expected Transmission Time (WCETT) [9]. The metric explicitly estimates the intra-flow interference among the links that uses the same channel. However, WCETT does not incorporate the inter-flow interference and load. In addition, WCETT is not isotonic and cannot compute loop free minimum weight paths. The Metric of Interference and Channel-switching (MIC) [12] metric addresses the drawback of The

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