Routing with Congestion Control Using Cross-layer Design in Wireless Mesh Network*

Wen Song, Xuming Fang

School of Information Science and Technology, Southwest Jiaotong University, Chengdu 610031, P. R. China
National Mobile Communications Research Laboratory, Southeast University, Nanjing, 210096, China
E-mail: {song__wen, xmfang2002}@163.com

Abstract

Wireless mesh network (WMN) is an innovative approach in packet radio networks. Routing is one of key challenging issues since the unpredictable behaviours of the medium and the network topology. In this paper two statistical MAC layer parameters are explored: available residual bandwidth and Frame Transmission Efficiency (FTE). A metric called Degree of Congestion Control is defined so that the routing algorithm can effectively search the better quality path with least congestion towards the final destination. A novel routing protocol called Least Congestion QoS-aware Routing (LCQSR) using cross-layer design approach is proposed to achieve a good trade-off between QoS aware and network performance based on DSR. The simulation results show that the protocol can improve the performance of network congestion effectively in terms of delay, packet delivery ratio and throughput.

Keywords: Wireless Mesh Network (WMN), congestion control, QoS aware, cross-layer design.

1 Introduction

Wireless mesh network (WMN) is a special case of mobile ad hoc network where the nodes have relative fixed positions and communicate to the Internet through one or more gateways. Due to the nature of previous routing algorithm, the traffic load for a mesh point may be extremely heavy during particular periods while the other mesh points are very lightly loaded. Consequently the overall performance of the network becomes poor even the total traffic load is far below the system capacity. In order to support the QoS and reduce the traffic congestion of networks, cross layer design method has been proposed [1-4]. The main idea is to send data at higher rate when the channel quality is good. Based on the cross layer design method, we proposed a novel routing protocol called Least Congestion QoS-aware Routing (LCQSR).

2 Related work

Due to the wireless channel and the user nodes movements, an effective and robust routing decision-making algorithm is needed to accommodate a large number of variables for dynamic resource allocation. Many issues of resource allocation such as capacity for QoS provisioning are discussed in [5-6]. There has been significant research toward the optimization and improving the QoS of multi-hop wireless networks as well. Most of above researches consider only some isolated components of the overall network. But the important interactions and dependencies among them are ignored. L. Iannone et al. try to use information of link quality from the lower physical layer for choosing a neighbor that has the best quality link to forward the data packet towards the destination. G. Holland et al. have proposed a rate adaptive MAC [7]. Their main idea is to send data at higher rate when the channel quality is good. In other words, selecting the rate at the MAC layer will be done to give the optimum throughput for the given channel conditions. Richard Draves et al. make use of MAC information and propose a Multi-Radio Link-Quality Source Routing (MR-LQSR) that explicitly accounts for the interference among links that use the same channel [8]. MR-LQSR employs a so-called Weighted Cumulative ET( WCETT) metric, but it has to propagate probe packets so that a great deal of network bandwidth resource must be consumed. Another possible metric is the Signal to Interference and Noise Ratio (SINR). For a given link and channel conditions, the packet error rate decreases as SINR increases. If the SINR is high, it may be possible to use higher data rates or use lower data rates with very low error rates. However, in general the SINR is not a good choice for determining the qualities of two different links, because the shadowing and fading characteristics depend heavily on the scattering environment between a transmitter and a receiver. Different links experience different multi-path propagation environments and hence different delay spreads. This leads to very different frequency selective fading characteristics for different links. The performance of 802.11a/g/n depends heavily on the frequency selectivity of the channel as they use coded OFDM for transmission. Lower values of SINR can support higher data rates than higher values of SINR depending on the channel model [9]. This was also observed in link level measurements of an 802.11b mesh network [10]. To specify a link's quality using the SINR, one must know what the underlying channel characteristics are. Another drawback is that the measured SINR at physical layer depends largely on the employed coding technique and its parameters. This limits the applicable conditions for higher protocols and the acquired information is not accurate too.

* This work was supported in part by the open research fund of National Mobile Communications Research Laboratory, Southeast University, China (N200608), SWJTU scientific research fund of China (2005B02), and SWJTU Innovation Practice Base for Postgraduate fund of Transportation Engineering of China.
3 Routing protocol and cross-layer design

A. LCQSR Protocol

Routing with congestion control is one of key challenging issues in WMN since the unpredictable behaviours of the medium and the network topology. Traditional DSR that pursues shortest route algorithm often causes network congestion [11]. In proposed LCQSR each node measures the medium usage and adds the information into the route request if it is in a congestion area. In this paper, congestion control is achieved in both MAC sub-layer and network layer, which is very different with the traditional congestion control done in transport layer. LCQSR intends to choose the shortest path with the highest degree of congestion control and least link congestion. It is supposed that the best quality links require the least number of retransmission for lost packets. Therefore, the network layer with this metric can prevent to waste the bandwidth for data transmission.

B. Cross-layer Design

In this paper two statistical MAC layer parameters are explored: available residual bandwidth and Frame Transmission Efficiency (FTE). The ratio of available residual bandwidth $\text{AvaRe}_\text{BW}(i)$ of mesh point/portal $i$ is measured by statistic free and busy time rate of the channel by utilizing virtual carrier sense. A mesh point/portal estimates its available bandwidth for new data transmissions. As Eq. (1) and (2), where channel bandwidth in link layer is $Bw_{\text{basic}}$; the ratio of channel free time is $T_{\text{idle}}$; and the overall time is $T_{\text{total}}$; $k$ is a weight factor. The weight factor is introduced due to the nature of 802.11. The DIFS, SIFS, and back-off time represent the overhead, which must be taken into account for each data transmission [12]. This overhead makes it impossible in distributed MAC competition scheme to fully use the available bandwidth for data transmission.

$$\text{AvaRe}_\text{BW}(i) = k \times Bw_{\text{basic}} \times \frac{T_{\text{idle}}}{T_{\text{total}}}$$  \hspace{1cm} (1)$$

$$k = \frac{\text{Data}}{\text{RTS} + \text{CTS} + (\text{Data} + \text{MACHdr} + \text{IPHdr}) + \text{ACK}}$$
$$= \frac{44 + 38 + (1500 + 52 + 20) + 38}{1500} \approx 0.8865$$

$$\text{AvaRe}_\text{BW}(i) = \alpha \times \text{AvaRe}_\text{BW}(i)_{\text{long}} + (1 - \alpha) \times \text{AvaRe}_\text{BW}(i)_{\text{short}}$$  \hspace{1cm} (3)

In our work, to compute residual bandwidth of node $i$ we use the exponentially weighted moving average algorithm to smooth the results, which uses joint predict and estimation with current sampled state information on time $k$ of node $i$ and the historical state information on time $k-1$, as Eq. (3), here $\alpha = 0.7$, and $\alpha \in [0, 1]$, then this may reduce parameter estimation errors. According to DCF retransmission mechanism of 802.11 we infer the link quality information from number of data retransmisions, and the congestion state information from the number of RTS retransmissions that are called ACKFailureCount and RTSFailureCount (Figure 1). Assume that in sending $f$-th packet from Node A to Node B the success rates are $FTE_{\text{QAB}}(i)$ and $FTE_{\text{CAB}}(i)$ respectively. We calculate these values as follows:

$$FTE_{\text{QAB}}(i) = \frac{1}{\text{ACKFailureCount}(i)+1}$$  \hspace{1cm} (4)$$

$$FTE_{\text{CAB}}(i) = \frac{1}{\text{RTSFailureCount}(i)+1}$$  \hspace{1cm} (5)

The two metrics are normalized values for success rates in sending the frames of Data and RTS successfully. A large number of retransmissions for RTS causes a small value of $FTE_{\text{CAB}}(i)$, to which we think that there is a congestion on the link of node A to B and with the same point, a small value of $FTE_{\text{QAB}}(i)$ leads the link of node A to B to be a low quality link. Obviously, in order to make routing algorithm converge quickly, when the number of retransmissions reaches to a predefined threshold, the source node gives up transmitting the packet and its related FTE is set to zero. Here we have the following formulas (as [13]):

$$FTE_{\text{QAB}}(i) = \alpha \times FTE_{\text{QAB}}(i-1) + (1 - \alpha) \times FTE_{\text{QAB}}(i)$$  \hspace{1cm} (6)$$

$$FTE_{\text{CAB}}(i) = \alpha \times FTE_{\text{CAB}}(i-1) + (1 - \alpha) \times FTE_{\text{CAB}}(i)$$  \hspace{1cm} (7)$$

$$FTE_{xy}(i) = FTE_{\text{QX}}(i) \times FTE_{\text{CX}}(i)$$  \hspace{1cm} (8)

For a multi-hop path from source node $S$ to the destination node $D$, $FTE_{\text{SD}}$ is made by multiplying $FTE_{xy}(i) (i = S, \ldots, D)$ along the path where $XY$ is the link between pairs of nodes along the path. The bottleneck bandwidth $\text{AvaRe}_\text{BW}_{\text{SD}}$ in the route can be obtained according to the relation of the end-to-end goodput from $S$ to $D$ with the number of hops [12]. Therefore, each node knows about the FTE and $\text{AvaRe}_\text{BW}_{\text{SD}}$ of multi-hop paths towards the destination and will decide to select the path with the maximum $\text{Congst}_{\text{path}}$ which is the least congested route with the best link quality (shown as Eq. (9), where $\beta$ is a balance parameter, and $\beta \in [0, 1]$).

$$\text{Congst}_{\text{path}} = \max(\beta \times FTE_{\text{SD}} + (1 - \beta) \times \text{AvaRe}_\text{BW}_{\text{SD}})$$  \hspace{1cm} (9)

4 Simulation results and analysis

To evaluate the performance of our LCQSR protocol, we perform simulations using NS2 [14]. We use 802.11 MAC
protocol with a channel data rate of 1Mbps, and the packet size used in our simulations is 512 bytes. Topology is shown as Figure 2, in which there are four mesh portals and the rest nodes are mesh points. Each CBR (Constant Bit Rate) data flow sends 10 packets per second (Table I). We change the number of data flows from 1, 3, 5, 7 to 10 to test different network performance metrics, such as average end-to-end delay and average end-to-end goodput (Figures 3–4).

![Network Topology for WMN Simulation](image)

5 Conclusions

This paper proposes a cross-layer routing protocol called LCQSR with a new metric integrating congestion control and QoS. It has the great potential of congestion control through conducting the flows from least congested area especially under high traffic loads. Another advantage of our approach over other cross-layer design methods is to estimate the channel quality without relying on the broadcast of extra probe packets.

References