Chinese Journal of Electronics
Vol.21, No.2, Apr. 2012

QoS Routing and Traffic Scheduling in Long-Distance 802.11 Wireless Mesh Networks*

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Abstract — Long-distance IEEE 802.11 wireless mesh networks are expected to provide multimedia traffic service in addition to basic Internet access, as more and more such networks have been emerged in real life. However, few work has been done on QoS provisioning in this area. In this paper, we propose QoS routing and scheduling algorithms to guarantee the QoS of real-time traffic. MQDSR (MAR-based QoS dynamic source routing) integrates bandwidth reservation and admission control, according to MAR bandwidth constraints model. We also present a service index to describe the QoS requirements for different traffic classes. Based on the service index, the scheduling algorithm is proposed to allocate the bandwidth in fine granularity. Simulation results in NS2 show that the proposed QoS routing and scheduling algorithms can provide QoS support in terms of end-to-end delay and throughput for traffic with high and normal priority, while avoiding the starvation of the best-effort traffic.

Key words — Long-distance wireless mesh network, 802.11, Quality of service (QoS), Routing, Traffic scheduling.

I. Introduction

Long-distance IEEE 802.11 wireless mesh (LDmesh) networks are emerging as a low-cost connectivity solution especially in sparsely populated areas and rural regions[1]. These networks are expected to provide multiple traffic services, including real-time traffic such as video-conferencing and VoIP in addition to basic Internet access. Real-time traffic has stringent bandwidth and delay requirements, therefore it is important to meet different QoS (Quality of service) requirements of traffic flows. However, many works focus on the MAC protocol design[1,2], few have addressed QoS issues in such networks.

We consider QoS dynamic routing and traffic scheduling in LDmesh networks. QoS routing could find a route that satisfies the end-to-end QoS requirements usually in terms of bandwidth or delay. Bandwidth sharing in wireless networks depends largely on MAC layer, therefore MAC protocol has an important impact on how to reserve bandwidth and admit a call. As a result, QoS routing designed for one type of MAC layer does not generalize to others easily. Bandwidth estimation is a challenging problem in an arbitrary wireless ad hoc network, since neighboring links using the same channel interfere with each other, and the interference relationships among all of the links in a network can be quite complex[3]. In LDmesh networks, inter-link interference model is different from that of wireless ad hoc networks due to its MAC protocol and point-to-point long-distance links[1]. The bandwidth estimation and admission control is still an open issue in LDmesh networks.

Traffic scheduling at MAC layer is an efficient scheme to support QoS and well studied[4−6]. However, in LDmesh networks, channel time is partitioned into rounds with SynRx and SynTx timeslots. Furthermore, data can be transmitted only in SynTx time slot to avoid inter-link interference[1]. Therefore, how to schedule traffic with different QoS requirements in such networks is also a challenging problem.

To address the first issue, we present MQDSR (Maximum Allocation with Reservation-based (MAR) QoS Dynamic Source Routing) for LDmesh networks based on 2P MAC[7]. In MQDSR, bandwidth estimation is designed leveraging MAR[8]. Admission control is thus straightforward once QoS route is established.

To solve the second problem, we define a service index for traffic with different QoS requirements, and propose a traffic scheduling algorithm based on the service index. The traffic scheduling algorithm further provides fine-granularity QoS guarantee in terms of delay and bandwidth.

The main contribution of our work lies in the cross-layer design of QoS routing and traffic scheduling in LDmesh networks. Although much work on this topic has been done in wireless networks[9], to the best of our knowledge, the paper is the first to introduce QoS routing and traffic scheduling in long-distance wireless mesh networks.

The performance evaluation of the proposed schemes were carried out in NS2 considering different network topology and various traffic pattern. The results are compared with a routing protocol without any QoS support.

*Manuscript Received Oct. 2011; Accepted Jan. 2012. This work is supported in part by the National Natural Science Foundation of China (No.61172063, No.61072063); and the Cultivation Fund of the Key Scientific and Technical Innovation Project, Ministry of Education of China (No.708024).

The paper is organized as follows. Section II describes MQDSR and the traffic scheduling algorithm in details. Section III evaluates the performance through extensive simulations. Section IV concludes the paper.

II. Cross-Layer Design of QoS Routing and Traffic Scheduling

We provide QoS support for real-time traffic across two layers: the network layer and the MAC layer. We will present them in detail as below.

1. MQDSR at the network layer

We proposed MQDSR: a MAR-based QoS Dynamic Source Routing protocol to provide QoS guarantee for real-time traffic in LDmesh networks[7].

(1) Bandwidth estimation

According to the MAR model, the unreserved link bandwidth and reserved bandwidth for each traffic flow should be calculated before admission control. We assume traffic flows are of constant bit rate, and assume that the QoS parameters such as class type, bandwidth and delay will be informed when a new traffic flow is generated.

When a traffic flow is generated, the ROUTE RE- QUEST packet carrying its QoS parameters will be broadcasted until it reaches the destination. If an inter- mediate node admits the traffic flow, it will reserve the request bandwidth in advance when it receives the ROUTE REPLY packet. The bandwidth reserved in advance is called by virtual reserved bandwidth, since it may not be used by flows actually.

The reserved link bandwidth for a traffic class with priority includes two parts: ① actual reserved bandwidth, and ② virtual reserved bandwidth. For traffic class c on link k, if there are n traffic flows to transmit, and virtual bandwidth has been reserved for m traffic flows, the reserved link bandwidth RB_{ck} is calculated as:

$$RB_{ck} = \sum_{i=1}^{n} AB_{ci} + \sum_{j=1}^{m} VB_{cj} \tag{1}$$

where AB_{ci} denotes the actual reserved bandwidth for flow i of type c. VB_{cj} denotes the virtual reserved bandwidth for flow j of type c.

Unreserved link bandwidth UB_k on link k is calculated as:

$$UB_k = B_k - \sum_{c=1}^{M} RB_{ck} - BE_k,$$

where B_k is the total link bandwidth. M is the maximum number of traffic class. BE_k is the bandwidth used by the best-effort traffic on link k.

Let UB_{ck} denote the unreserved link bandwidth for a traffic class c on link k, then

$$UB_{ck} = UB_k - \lambda T_k$$
$$\lambda = \begin{cases} 0, & \text{if } RB_{ck} < BC_{ck} \\ 1, & \text{otherwise} \end{cases} \tag{2}$$

where T_k refers to the reservation bandwidth threshold and BC_{ck} is the bandwidth constraint for traffic class c on link k.

The unreserved path bandwidth UB is defined as the minimum unreserved link bandwidth for all the links along the path. Similarly, the reserved path bandwidth for traffic class c RB_c is defined as the minimum reserved link bandwidth for that traffic class for all the links along the path. That is

$$UB = \min_k UB_k$$
$$RB_c = \min_k RB_{ck}$$

(2) Admission control

Bandwidth reservation and admission control is implemented during the route discovery process. The ROUTE REQUEST packet with QoS parameters is copied to all the interfaces of the source node. The admission control in source nodes is shown in Fig.1.

Algorithm 1 Admission control in source nodes
(1) A new traffic flow with class type c, request bandwidth r
(2) Make ROUTE REQUEST packet
(3) **for** each of its interfaces **do**
(4) Calculate UB, RB_c and BC_c on the link
(5) **if** ($RB_c \leq BC_c$, and $r \leq UB$) or ($RB_c > BC_c$ and $r \leq UB_c - T_k$) **then**
(6) Admit
(7) Update UB and RB_c in the ROUTE REQUEST packet.
(8) Transmit it.
(9) **else**
(10) Drop it
(11) **end if**
(12) **end for**

Fig. 1. Algorithm 1

When an intermediate node receives the ROUTE REQUEST packet from one interface, it will copy the packet to all other interfaces. Each interface decides whether to admit it or not independently according to the MAR bandwidth constraints model as that in source nodes.

If the destination receives the ROUTE REQUEST packet, it will make a ROUTE REPLY packet. The ROUTE REPLY packet eventually reaches the source. If there are multiple paths, the path with maximum reserved path bandwidth for high and normal priority traffic is selected. For the best-effort traffic, the path with maximum unreserved path bandwidth is selected.

2. Traffic scheduling algorithm based on service-index at the MAC layer

Although QoS routing can provide an end-to-end route with rough QoS guarantee, it is hard to guarantee the bandwidth in fine-granularity. To this end, we propose a traffic scheduling mechanism at the MAC layer to decide how and which packets are transmitted at each round.

(1) Service index

The QoS requirements of real-time traffic can be described as its data rate and its maximum tolerable delay. Suppose a real-time traffic has data rate of R, and maximum tolerable delay of D. The data are partitioned into packets equally with size of P_d excluding header. In order to provide continuous transmission for real-time traffic, $B(\approx R \times D/P_s)$ packets should be delivered during time D. Since time is partitioned into rounds with length of T_r under 2P-based MAC, B packets should be transmitted in $I(\approx D/T_r)$ rounds to meet the delay requirement. Therefore, we have the following definition of service index.

Definition 1 (I, B) is defined as real-time traffic's service index in 2P-based wireless mesh networks, where I is the service interval, B is the number of packets served during I.

$$I = \lceil D/T_r \rceil, B = \lceil R \times T_r \times I/P_d \rceil$$

Take real-time audio traffic for example. The data rate R is particularly 384kbps for high definition music. The maximum tolerable delay D is 150ms. In 2P, time slot is usually 20ms, and packets size is about 1400 bytes without header. One round includes two time slots, so $T_r = 40$ms. Audio packets are usually as small as tens of bytes. To achieve high efficiency, short audio packets are aggregated into $P_d = 1400$bytes. According to the definition, its service index is (6, 4). That is, 6 packets should be delivered in 4 rounds.

(2) Traffic scheduling algorithm

We still consider three traffic classes: high, normal and best effort. The high priority traffic is most sensitive to delay, such as interactive real-time audio/video application. The normal priority traffic has relaxed delay bounds, such as stored audio/video. The best-effort traffic has no limitations on the delay. To meet requirements of different traffic, we schedule the packets transmitted in each round according to their service index.

We firstly calculate the service indexes for high and normal priority traffic. For high priority traffic with service index (I_h, B_h), we schedule at least N_h packets in one round in order to guarantee their bandwidth, where $N_h = \lceil B_h/I_h \rceil$.

For normal priority traffic with service index (I_n, B_n), packets are scheduled with more flexibility. It is enough to transmit B_n packets in I_n round.

For the best-effort traffic, the packets scheduled in one round are $N - N_h - N_n$. N is calculated as follows.

According to 2P MAC, a round consists of two time slots for SynRx and SynTx phases. Time slots are fixed, therefore the available bandwidth seen by the application layer BW_{app} is:

$$BW_{app} = \frac{BW_{mac}}{2 \times P_d/(P_d + P_h)},$$

where BW_{mac} is the bandwidth at MAC layer, P_d is the length of the data and P_h is the header length from MAC layer to the application layer.

Therefore, the number of packets that can be transmitted in one round is at most N,

$$N = BW_{app} \times T_r/P_d$$

Since we use the MQDSR to guarantee the bandwidth for the real-time traffic, the best-effort traffic will not be starved, *i.e.*, $N - N_h - N_n > 0$.

III. Performance Evaluation

We evaluated the performance of the proposed QoS routing and scheduling algorithms in NS2. The MAC layer is modified to support 2P MAC protocol. The MQDSR is implemented based on the extension of DSR supporting multiple interfaces. The traffic scheduling algorithm is implemented based on 2P MAC protocol. The results are compared with that of MDSR (Multi-interface DSR) without QoS support or traffic scheduling.

Three traffic classes are considered here: high priority, normal priority and the best effort. The CBR traffic with different priority is used in the simulation. The sending rate of each CBR flow is set to 291.2kbps, and the packet length is 1400 bytes (26 packets per second). For the high priority traffic, the 1-hop tolerable delay D_h is about 80ms. The round time T_r is also set to D_h. Therefore the service interval I_h is 1, packets sent in one round is 2 according to Eq.(3). The service index for the high priority traffic is thus (1, 2). For the normal priority traffic, the tolerable delay is set to $2 \times T_r$, so its service index is (2, 4), that is to say, 4 packets should be transmitted during 2 rounds. For the best-effort traffic, there is no service index.

The performance metrics are the end-to-end delay for each flow and the aggregated throughput for each traffic class. The aggregated throughput is referred to the total throughput of all the flows with the same priority.

We firstly employ a linear topology with 4 nodes to verify the QoS routing and traffic scheduling algorithms. We consider how the CBR traffic and FTP traffic work with the algorithms. Then a mesh topology with 14 nodes is used, which is bipartite and fault-tolerant. The performance are evaluated through extensive simulations.

1. Linear topology

In this scenario, there are 4 nodes placed in a line, denoted

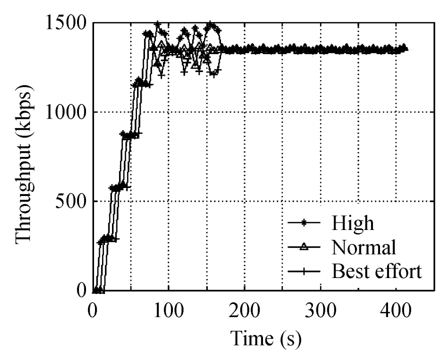

Fig. 2. Aggregated throughput without QoS support

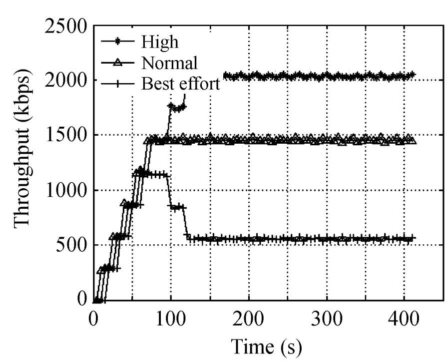

Fig. 3. Aggregated throughput with QoS support

as node 0 to node 3 sequentially. We first use CBR traffic for all the three traffic class, then we use FTP as the best-effort traffic, to see if the algorithms can work well with FTP traffic, which is a primary traffic type.

Simulation time is 400s. All the traffic flows are from node 0 to node 3. At 5s, node 0 starts a high priority traffic, then after 5s, starts a normal priority traffic, after 5s again, starts a best-effort traffic, and so on, until it generates 30 traffic flows in total. The simulations are carried out with and without the proposed mechanism. The end-to-end delay and the aggregated throughput are calculated in node 3.

(1) CBR as best-effort traffic: We first consider the scenario where all the three classes of traffic are CBR. Fig.2 shows the aggregated throughput without QoS support. We can see that all 30 flows are accommodated. At the beginning, the aggregated throughput of each traffic type increases till the network is saturated at about 80s. Then all the flows contend the bandwidth, after 170s they share the bandwidth almost fairly. The average delay also illustrates the same result. With QoS support, only 17 flows are admitted to the network. As shown in Fig.3, the bandwidth of high priority flows are guaranteed. The normal priority flows are also allocated enough bandwidth. The best effort flows enjoy the left bandwidth avoiding starvation due to the MAR bandwidth constraints. The end-to-end delay of high and normal priority traffic is very small. The above results show that the aggregated throughout and the end-to-end delay are improved efficiently under our QoS scheme.

(2) FTP as best-effort traffic: We then examine the scenario with FTP as the best-effort traffic. The results are similar to that using CBR. For the limited space, figures are omitted here.

2. Mesh topology

The network topology used is as shown in Fig.4. Node 0 and 1 are gateway nodes located at the center, providing connectivity to the Internet. The topology is a multi-stage graph, and is bipartite.

Simulation time is 200s. The node 11, 12 and 13 start CBR flows to a destination in the Internet (not shown in Fig.4). We collected the performance metrics at the destination node, and also the traffic load at gateway node 0 and 1.

Fig.5 is the aggregated throughput without QoS support. We can see that the throughput of each traffic class shows the same trend, since there is no admission control in MDSR, each flow contends the bandwidth fairly. Almost all the end-to-end delays are longer than 1s, even to 4s.

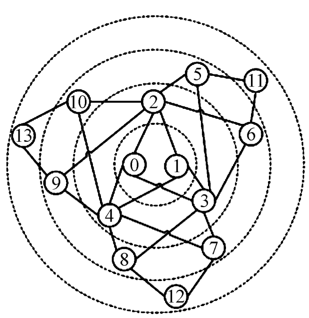

Fig. 4. Mesh topology

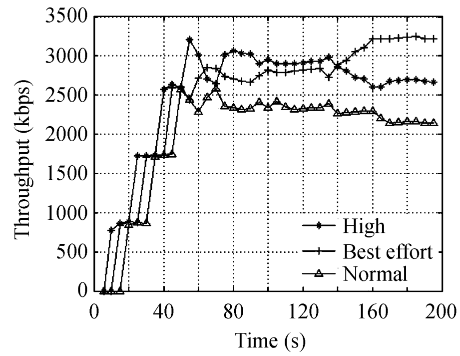

Fig. 5. Aggregated throughput without QoS support in the mesh topology

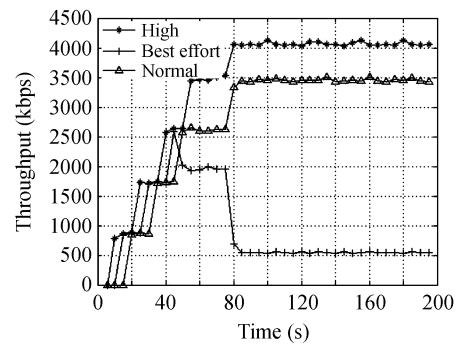

Fig. 6. Aggregated throughput with QoS support in the mesh topology

Fig.6 is the aggregated throughput with QoS support. MQDSR differentiates traffic flows with different priorities. The aggregated throughput of the flows with high priority is the maximum. Before 50s, the available bandwidth in the network is abundant, therefore all the flows share the bandwidth fairly, hence the aggregated throughput of each traffic class increases in the same manner. At 80s, the aggregated throughput of the best-effort traffic falls, because the bandwidth is not so abundant, the traffic with high priority preempts the bandwidth of the best-effort. However, the best-effort flows still keep a fixed throughput, since a small bandwidth (reservation bandwidth threshold) is reserved for the best effort traffic to avoid their starvation. The end-to-end delays of all the traffic flows with priority are shorter than 1s. However, for best-effort traffic flows, the end-to-end delay is much longer with average of 3.397s. This is due to the traffic scheduling algorithm.

IV. Conclusion

In this paper, we designed QoS routing and traffic scheduling to provide the QoS support for different traffic classes in long distance wireless networks. Although MQDSR and the traffic scheduling are deployed for 2P-MAC based network, it can be applied in other long distance wireless networks as long as the MAC is based on 2P. In the future, we will deploy MQDSR in our test-bed to verify its performance further and explore its application in real world LDmesh networks.

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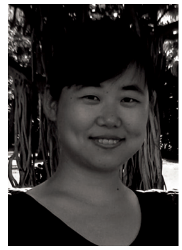

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