A new medium access control scheme at relay nodes for throughput improvement in wireless mesh networks

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Abstract: The wireless mesh networks have been a very promising solution for providing last few miles wireless connectivity in the metropolitan area networks. A new medium access control scheme is proposed to improve throughput in wireless mesh networks. The proposed scheme is to adjust the minimum size of contention window of mesh clients according to the information of transmission queue at relay nodes. The relay node carries the load information on an ACK frame by using the reserved subtype fields. The proposed scheme gives a priority to the relay node for transmitting packets when the relay node becomes a bottleneck. The simulation results show much better performance from the proposed scheme in comparison with that from original CSMA/CA scheme.

Keywords: wireless LANs, CSMA/CA, mesh network, IEEE 802.11

Classification: Wireless circuits and devices

References

1 Introduction

The wireless mesh network is an emerging technology for providing last few mile wireless connections in metropolitan area. It is low cost solution and it has both ad-hoc networking characteristics and infrastructure natures [1].

The wireless mesh network consists of wireless mesh routers and mesh clients. The mesh clients can be connected to the mesh routers with wireless or wired links. The links between mesh routers are wireless. Some of the mesh routers are connected to the Internet, which are called as gateway mesh routers. Fig. 1 shows the basic architecture of wireless mesh networks.

![Wireless mesh networks architecture](image)

**Fig. 1.** Wireless mesh networks architecture

The main MAC protocol of IEEE 802.11 wireless mesh network is CSMA/CA (carrier sense multiple access with collision avoidance) scheme [2]. The stations to send a packet in original CSMA/CA protocol specified in IEEE 802.11 standards generate backoff time as following.

\[
\text{Backoff Time} = \text{Random()} \times T_{\text{slot}}
\]

where \( \text{Random()} \) is a randomly selected integer from a uniform distributed interval \([0, CW]\) where \( CW \) (Contention Window) is an integer that is set to the minimum \( CW_{\text{min}} \) value initially. If the transmitted packet is collided with other packets, the CW value is doubled and the new random backoff time is determined. The CW has a maximum \( CW_{\text{max}} \) value. \( T_{\text{slot}} \) is a slot time which is specified differently according to the physical layers.

IEEE 802.11 task group “s” has been investigating wireless mesh networks as an amendment [3]. Though the IEEE 802.11s is ongoing standard, many improvements have been made for the wireless mesh networks.

The IEEE 802.11s supports multi-hop forwarding with six MAC addresses at MAC layer. Also, optional medium access method and some security issues are proposed.

2 Bottleneck problem in Wireless Mesh Networks

Because the wireless mesh networks seem to be the right solution to provide wireless connectivity in metropolitan area networks, there have been many research interests in the various topics of wireless mesh networks. Routing protocols, channel assignment and scheduling methods have been research topics and the jointly optimizing of these schemes was also presented [1].

However, a few studies on the bottleneck problem at relay nodes in wireless mesh networks are considered so far. The bottleneck problem occurs at a mesh router acting as a relay node when the incoming traffic rate is much higher than outgoing traffic rate, which makes the network performance to be degraded.

In [5], the authors proposed a method to avoid the bottleneck at relay nodes by controlling CTS response. The relay node responds to a RTS packet only in the case that the balance condition is satisfied by monitoring the receiving rate and forwarding traffic rate. The balance condition is an inequality that the difference between incoming rate and outgoing rate should be less than a predefined value. This method requires no changes in the standard but the relay nodes need to monitor the traffic rate and calculate the balance condition every some interval. Moreover, the RTS/CTS transmission scheme is not used generally in common IEEE 802.11 wireless LANs devices.

The authors in [6] present an analysis of bottleneck delay and throughput in wireless mesh networks. They considered linear and grid wireless mesh topologies in which there is no interference between mesh routers by assigning non-overlapped channels. The results show the limited number of gateway nodes could be the bottleneck of the entire networks. However, to assign different wireless channels between mesh routers is not practical. Using the same frequency channel between mesh routers is more sensible.

The authors in [7] proposed a bottleneck-first scheduling method in the OFDMA-based backhaul wireless mesh networks. Although the OFDMA scheme has different physical characteristics from CSMA/CA protocol, the proposed heuristic scheduling algorithm allocates resource to maximize the throughput.

Most researches assume that the links between mesh routers do not interfere with the wireless link between mesh routers and mesh clients. However, the dual wireless transceiver may cause a price rise and common access points (APs) support only one RF transceiver. Therefore, an environment where mesh routers and mesh clients share the same wireless channel should be considered.
3 Proposed medium access control scheme at relay nodes in wireless mesh networks

The CSMA/CA based MAC protocol is considered for mesh clients and routers. Even though CSMA/CA protocol is not suitable for multi-hop transmissions, it is still important since existing IEEE 802.11 wireless LANs devices can be used.

The new medium access control scheme at relay nodes is proposed to alleviate the bottleneck problem. The relay nodes check the transmission buffer and send an ACK packet carrying the buffer state information. For the sake of simplicity, the transmission buffer state at the relay node is divided into two categories. One is high load condition in which the buffer queue size is larger than a half of the predefined buffer capacity. The other is low load condition. Therefore, two kinds of ACK frames are needed. In the view of IEEE 802.11 standards, the ACK frame consists of frame control, duration, RA (receiver address) and FCS (frame check sequence) fields. In the frame control field, type (2 bits length) and subtype (4 bits length) subfields are included. The ACK frame is a control type as presented with ‘01’ and its subtype is an ACK with ‘1101’. The subtypes with range of ‘0000’-‘0111’ are reserved. Thus two reserved subtypes may be used for the ACK frame carrying buffer state information. In other words, the subtype with ‘0000’ is used as the ACK frame with high load condition at receiver and the subtype with ‘0001’ may be used for the low load condition. By adopting these modifications, no additional fields or bits are needed at the ACK frame.

According to the load information of a relay node included in the ACK frame, the mesh clients adjust the $CW_{min}$ value. In the case that the mesh client which transmitted a data packet to a relay node receives an ACK frame carrying the information of high load condition, the mesh client doubles the current $CW_{min}$ value. The wider range of contention window makes the client’s transmission probability to be lower, so the relay node has a high priority for sending packets of the transmission queue. The maximum value of $CW_{min}$ is set to $CW_{max}$. On the other hand, if the mesh client receives the ACK frame with low load condition, the client resets the $CW_{min}$ value to the default value. The proposed medium access control scheme is shown in Fig. 2.

4 Performance Evaluation and Results

This paper considers multiple mesh clients and one mesh router which acts as a relay node. The relay node transmits packets to a gateway mesh router that is a sink node. The mesh clients and mesh router share the same wireless channel and they use CSMA/CA protocol as MAC protocol specified in IEEE 802.11 wireless LANs standards. In the performance evaluation, the RTS/CTS transmission scheme is not considered but the DATA/ACK transmission sequence is used. The collisions occur when more than two stations transmit packets simultaneously since the capture effect is not considered. The radio coverage of mesh clients includes the gateway mesh router which
Fig. 2. Proposed medium access control scheme

means that the relay node’s packet transmission to the sink node is interfered by the mesh clients’ packet transmissions. The traffics go one-way from mesh clients to the sink node via the relay node.

Each mesh client generates 1000 bytes length packets with mean inter arrival time of 20 msec, which makes about 400 kbps traffic rate per a mesh client. The IEEE 802.11b physical layer with a 11 Mbps peak rate is used. The $CW_{min}$ is fixed as 15 and the $CW_{max}$ is set to 1023. The relay node has a transmission buffer of 32 KBytes. The OPNET simulator is used for the evaluation, which is a reliable commercial communications network simulation tool. The existing IEEE 802.11 wireless LANs station node is reused with some protocol modifications according to the proposed scheme.

The throughput is defined as the traffic rate of the successfully received packets at each node. Since the packets from mesh clients should be delivered to the sink node through the relay node, the throughput at the sink node is important. As shown in Fig. 3, the throughput at the relay node increases until 7 mesh clients in both cases of the proposed scheme and original scheme as the number of the mesh clients increase. However, after the
wireless link capacity is saturated the throughput at the sink node is dramatically decreased in the case that the original CSMA/CA protocol is used. On the contrary, the throughputs of the relay node and the sink node in the proposed scheme are almost same, which means that most of the traffics from the mesh clients are forwarded to the sink node by the relay node. Because the proposed scheme makes the initial contention window size of mesh clients to be doubled when the relay node suffers from a bottleneck, the relay node can obtain a higher medium access priority than the mesh clients, which results in the relay node’s quick forwarding of the received packets.

5 Conclusions

In this paper, a new medium access control scheme for throughput improvement is proposed in wireless mesh networks. The mesh router with a relay function transmits an ACK packet to mesh clients carrying its own buffer information which indicates that the relay node suffers a bottleneck or not. The mesh clients adjust the $CW_{\text{min}}$ value according to the relay node’s buffer state in the ACK packet. The proposed scheme has an effect that the relay node can transmit its traffic more quickly to the sink node than mesh clients’ transmissions when it suffers a bottleneck. The simulation results show that the total throughput at the sink node is much higher than that of the original scheme using CSMA/CA protocols.

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