Multi-Rated Packet Transmission Scheme for IEEE 802.11 WLAN Networks

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Abstract. In a multirate wireless network such as IEEE 802.11 WLAN, the connection having a good channel condition uses a high transmission rate and the connection having a poor channel condition uses a low transmission rate. However, this coexistence of different transmission rates degrades the total system performance of the network. In order to eliminate this performance abnormality and improve protocol capacity, we propose a new packet transmission algorithm, the RAT (Rate-Adapted Transmission) scheme. The RAT scheme distributes the wireless channel fairly based on the channel occupancy time. Moreover, it efficiently transmits packets even in a single station using rate-based queue management. Therefore, the RAT scheme obtains not only the inter-rate contention gain among stations but also the intra-rate contention gain among connections in a single station. By simulation, we show that the proposed RAT scheme is superior to the default IEEE 802.11 MAC DCF access method and the modified OAR (Opportunistic Auto Rate) scheme.

1 Introduction

Recently, WLAN (Wireless LAN) has achieved tremendous growth and has become the prevailing technology for wireless access for mobile devices. WLAN has been rapidly integrated with the wired Internet and has been deployed in offices, universities, and even public areas. Moreover, the IEEE 802.11 WLAN standard is considered as the most popular wireless access method for ad-hoc mobile communications.

The wireless channel condition varies over time and space due to the dynamic features of the wireless environments such as mobility, interference, and location. To cope with this channel variation, the physical specifications of the IEEE 802.11 WLAN provide multiple transmission rates by employing different channel modulation and coding schemes. The IEEE 802.11b standard [1] provides four different physical transmission rates from 1Mbps up to 11Mbps. The IEEE 802.11a [2] and 802.11g [3] standards provide eight different transmission rates from 6Mbps up to 54Mbps. This multiple rate capability enables a wireless station to dynamically choose a physical transmission rate depending on the channel condition.

The efficient selection of the physical transmission rate affects the WLAN performance significantly. To choose the best rate among multiple transmission rates at a given time, numerous rate control algorithms have been proposed [5–12]. These algorithms enhance the WLAN performance by dynamically changing transmission rates according to the variable channel conditions. However, problems still exist. Although these rate control algorithms efficiently utilize the wireless medium, there is consider-able performance degradation when some connections transmit data at lower physical rates than others. This performance degradation with mixed transmission rates is due to the CSMA/CA protocol, which is used in the IEEE 802.11 MAC DCF (Distributed Coordination Function) channel access method [4].

Therefore, in this paper, we investigate this performance abnormality. We then propose a novel packet transmission strategy for improving protocol capacity in multi-rate wireless networks.

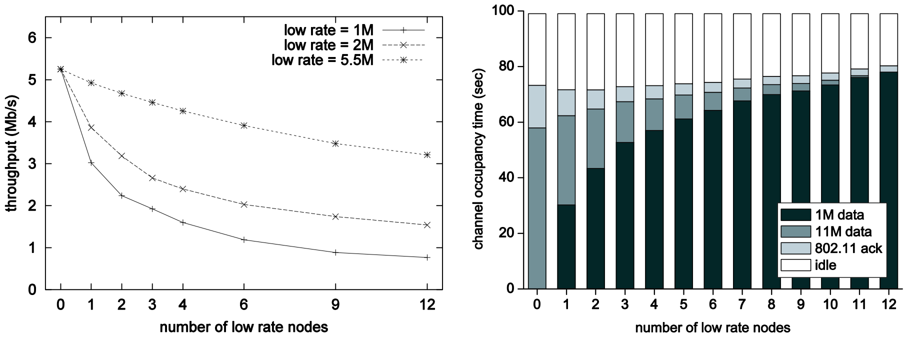
2 Background and Motivation

2.1 Performance Abnormality with Multiple Transmission Rates

For investigating the performance abnormality, twelve mobile stations send data frames to wired stations over the WLAN AP (Access Point). The default transmission rate is set as 11Mbps. We started the experiments without low transmission rate nodes and thereafter increased the number of low rate nodes gradually.

Fig. 1(a) displays the result of the experiments with multiple transmission rates. When there is no low transmission rate node, the total system throughput is 5.253 Mbits/s. However, the throughputs are degraded drastically when the number of low rate nodes is increased. In particular, the throughput is degraded by almost half even when only one 1Mbps rate node is involved in the transmissions.

Fig. 1(b) shows he channel occupancy time when 11Mbps and 1Mbps rates are mixed in the same experiment. On average, about 77 % of the total time is used for actual data transmission and the other time is idle. In the figure, the portion of 1Mbps data is increased as the number of 1Mbps rate nodes is increased. However, the time portion used by 1Mbps nodes increases exponentially corresponding to the number of 1Mbps nodes. This nonlinearity is because the IEEE 802.11 MAC DCF channel ac-cess method, which is founded on the CSMA/CA protocol, equally distributes the wireless channel based on access probability. The uniform channel access probability guarantees long term fairness when all connections use the same transmission rate. However, if the transmission rates of connections are different, the low rate connection requires more channel resources than the high rate connection to send the same amount of data. Consequently, if the channel access probability is equal, the low rate connection captures the channel much longer than the high rate connection and the fairness is broken. In this situation, the wireless medium is not fully utilized and the total system throughput is considerably degraded even when only few low rate connections are involved in transmissions [13].



(a) Throughput degradation

(b) Channel occupancy time

Fig. 1. Performance degradation with multiple transmission rates

2.2 Related Works

In efforts to improve the performance of the IEEE 802.11 WLAN, many researchers have studied the WLAN protocol and have proposed new algorithms. They analyzed system throughput of IEEE 802.11 DCF MAC protocol [13–15] and proposed numerous new algorithms to improve the WLAN performance from many points of view such as fairness, service differentiation, and system throughput [5–12].

As noted earlier, all IEEE 802.11 physical specifications support variable data transmission facility at multiple rates. A simple way to select the best physical transmission rate is to change the rates based on the history of successes or failures of previous packet transmissions. The representative algorithm based on this proactive approach is the ARF (Auto Rate Fallback) scheme [5]. The ARF scheme is simple and easy to implement. However, it does not prevent performance degradation when the transmission rates are mixed. Furthermore, the ARF scheme cannot react quickly when the wireless channel condition fluctuates.

The RBAR (Receiver-Based Auto Rate) scheme [6] is another rate adaptation algorithm for improving WLAN system performance. RBAR uses feedback information from the receiver to sense the wireless channel conditions. Due to the more accurate channel estimation, the RBAR scheme yields significant throughput gains compared to the ARF scheme. However, the RBAR scheme also fails to cope with the performance degradation with multiple transmission rates. It does not consider the throughput degradation arising from data transmission of low rate connections.

The OAR (Opportunistic Auto Rate) scheme [7] attempts to maximize the system performance by exploiting a good quality channel via burst packet transmissions. The OAR scheme opportunistically transmits multiple packets in a burst whenever the channel quality is good. Due to the opportunistic gain, the OAR scheme outperforms the RBAR and is enable to handle the performance degradation arising from multiple transmission rates. However, in the OAR, a burst packet transmission is only possible when the packets queued in the network interface have the same destination. There is little performance gain when most stations have packets destined for more than one station such as downstream traffic in an infrastructure topology and all traffic in an ad-hoc topology.

The RBAR and the OAR schemes require a modified RTS / CTS mechanism for channel estimation. Instead of the signal quality of the RTS frames, the SNR (Signal to Noise Ratio) scheme [8] estimates the channel quality using the received signal strength measured from the received frames. Accordingly, the SNR scheme does not require the RTS / CTS mechanism or any change in the current IEEE 802.11 WLAN standard. However, the SNR scheme is a link adaptation scheme only. It does not consider the performance degradation arising from multiple transmission rates.

A simple solution for solving the performance abnormality problem is to combine the OAR and the SNR schemes. By simply combining the OAR and SNR schemes, we can arrive at a new feasible solution for preventing the performance degradation with-out modification of the existing standard. We call this solution the MOAR (Modified OAR) scheme. However, the MOAR scheme still has limitations originated from the original weaknesses of the OAR scheme. Even though the MOAR scheme avoids the performance abnormality with multiple transmission rates, it is only effective when the station transmits packets to only one destination and the serialized packets in the queue head to the same station. This limitation restricts the performance gain considerably in dynamic wireless networks such as ad-hoc networks. Therefore, we propose a new packet transmission strategy for improving IEEE 802.11 WLAN protocol capacity in a multiple rate network.

G. Tan and J. Guttag have proposed TBR (Time Based Regulator) scheme [16] that removes the performance degradation in multiple destined packet environments. However, the TBR scheme does not work in ad-hoc networks. It only runs on the AP and matches just with infrastructure topology. It cannot improve performance when distributed nodes content each other to transmit packets. In addition, the TBR scheme requires the slight modification of the existing MAC standard in case of only existing upstream one-way traffic such as UDP. Therefore, we propose a new packet transmission strategy for improving IEEE 802.11 WLAN protocol capacity in a multiple rate network.

3 Rate-Adapted Transmission Scheme

When multiple stations contend for a channel in the IEEE 802.11 WLAN, the default DCF MAC access method probabilistically gives an equal chance for channel access to all stations. This channel distribution method, however, degrades the system performance severely when stations use multiple transmission rates together. In multiple rate transmissions, the packet transmission at a low rate occupies the channel too long in comparison to packet transmission at a high rate. Therefore, the RAT scheme at-tempts to share the channel based on the occupancy time rather than access opportunity. Accordingly, when multiple stations with different transmission rates contend to obtain the channel, the RAT scheme grants the stations constant channel occupancy time. Thus, the stations at a high rate multiply transmit as many packets as possible within the granted occupancy time. We call this capacity improvement the inter-rate contention gain.

Even in a single station, performance degradation occurs when multiple connections with different rates contend to transmit packets. In the IEEE 802.11 WLAN, a station transmits packets sequentially based on the arrival sequence order. However, when multiple packets at different rates are transmitting in a station, the packet at a low transmission rate occupies the channel for a long time and blocks fast packet transmissions at high transmission rates. As a result, the high rate connection is deprived of its share by the low rate connection and the total system performance of the WLAN is degraded. To avoid this performance degradation, the RAT scheme adopts rate-based queues. Through the rate-based queues, the RAT scheme sends packets adaptively depending on the physical transmission rates in a station. When a packet comes into the network interface, the RAT scheme classifies the packet according to the physical transmission rate of its connection and inserts the packet into one of the rate-based queues. Then, when the station obtains the channel, the RAT packet scheduler selects the appropriate rate queue and transmits multiple packets in the queue up to the channel occupancy time. Consequently, the high rate connection is not interfered with by the low rate connection. We call this capacity improvement the intra-rate contention gain. Fig. 2 describes in detail the RAT algorithm.

4 Simulation Experiments

Through simulations, we compared our RAT scheme with the default DCF MAC access method and the MOAR scheme in the simulations. We modified an NS simulator [17] to follow the IEEE 802.11b WLAN parameters.

4.1 Network Topologies

First, we evaluated the system performances according to the network topologies, an infrastructure topology and an ad-hoc topology, shown in Fig. 3. The infrastructure topology has one AP and many mobile nodes. The AP is located in the center of the mobile nodes and functions as a centralized controller. Thus, the downstream traffic is delivered from the AP to the mobile nodes and the upstream traffic is delivered from the mobile nodes to the AP.

In the infrastructure topology, we measured the total system throughputs with mixed physical transmission rates. For the experiment, the AP connects with 20 mobile nodes. The default rate of each connection is 11Mbps, the highest physical transmission rate. The rate for the low connection is 1Mbps, the lowest physical transmission rate. Each connection sends 300Kbits UDP data per second. The unit of channel occupancy time for the MOAR and RAT schemes is 8ms.

```
while (the data queue is non-empty) {
    // T_unit is allowed occupancy time per connection
    T_used := 0;        // used occupancy time
    rq_s := select_ rate_queue();
    n_c := number_of_connections(rq_s);
    rate_tx := trasmission_rate(rq_s);    // transmission rate of rq_s

    do {
        f_d := dequeue(rq_s);
        T_used += (f_d.length / rate_tx);
        enque(que_tx, f_d);
        if (head_frame(rq_s).dst != f_d.dst) {
            while (que_tx is non-empty) {
                f_tx := dequeue(que_tx);
                do {
                    result := transmit(f_tx);
                } while (result != success);
                if (que_tx is non-empty) {
                    idle(t_SIFS);
                }
                else {
                    idle(t_DIFS);
                }
            }    // end of while
        }    // end of if
    } while (T_used < T_unit  * n_c);
}
```

Fig. 2. The RAT scheduler algorithm

Fig. 4(a) depicts the system throughput for upstream traffic in the infrastructure topology. In the figure, the vertical axis represents the total system throughput and the horizontal axis represents the ratio of the number of low rate nodes to the number of total nodes. As the results indicate, the default DCF MAC access method degrades system throughputs severely in proportion to the number of low rate nodes. This drastically decreases the system performance even when only a few nodes send data at 1Mbps. However, the MOAR and RAT scheme are not seriously affected by the low rate nodes. They yield smooth degradation of the system throughput depending on the number of 1Mbps rate nodes. This is because, when multiple stations with different rates contend for the channel, the MOAR and RAT schemes extract the inter-rate contention gain by distributing the channel based on the occupancy time.

Fig. 4(b) displays the system throughput for downstream traffic in the infrastructure topology. In this experiment, the AP transmits packets to all mobile nodes. Similar to the upstream experiment, the default DCF method does not have good performance in the downstream traffic. Moreover, the MOAR scheme shows poor performance corresponding with that of the default DCF method. However, the RAT scheme displays good performance in comparison to the other

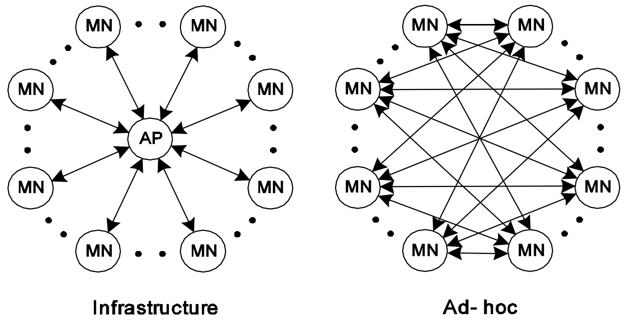
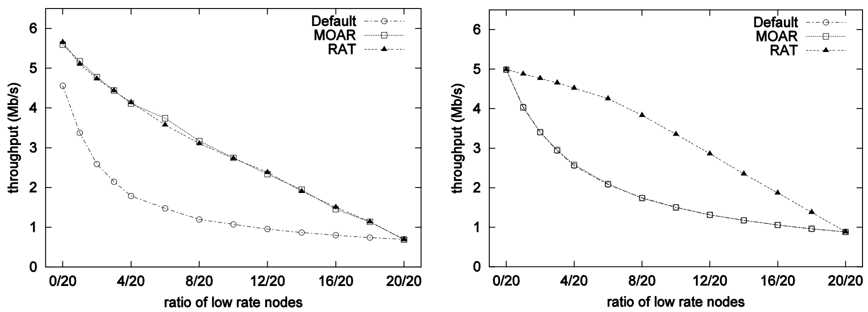


Fig. 3. Network topologies



(a) Upstream traffic

(b) Downstream traffic

Fig. 4. System throughput in infrastructure topology

two schemes. As noted earlier, the MOAR scheme distributes the channel based on the occupancy time. Thus, it has good performance when faced with inter-rate contention. The MOAR scheme, however, does not consider the case where the multiple connections at different rates contend to send packets in a single node. It does not improve system performance at all when connections in a single station contend to send packets with multiple transmission rates. On the other hand, the RAT scheme adaptively transmits packets based on the physical transmission rates. It sends multiple packets for high rate connection using rate-based queue management even in a single station. Accordingly, the RAT scheme improves protocol capacity when faced with an intra-rate contention environment as well as an inter-rate contention environment.

For the next simulation, we evaluated the system performance in the ad-hoc net-work topology. In the ad-hoc topology, the mobile node transmits data to other mobile nodes in distributed manner without the centralized AP. Thus, every node simultaneously sends packets to multiple nodes at different rates. Fig. 5 shows the results of total system throughput in the fully connected ad-hoc network topology. As can be seen in the figure, the results are similar to those of the downstream traffic in the infra-structure topology. The default DCF method and the MOAR scheme show poor performance. However, the RAT scheme shows better performance than the other schemes even in the ad-hoc network topology.

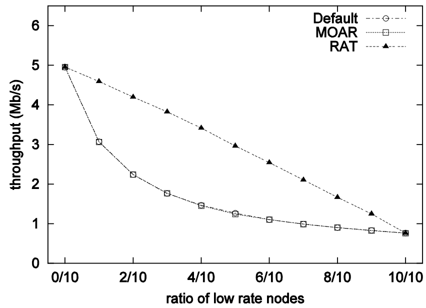
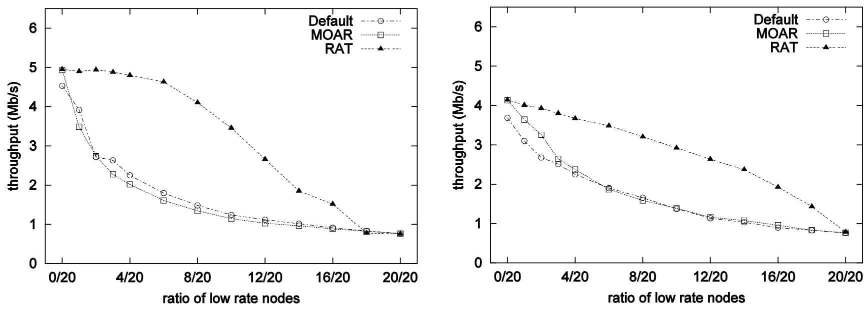


Fig. 5. System throughput in ad-hoc network topology

4.2 TCP Traffic

In this section, we evaluated the system performance with TCP traffic type using FTP. Fig. 6(a) shows the system throughputs for the upstream TCP traffic in the infrastructure network topology. Hence, the mobile nodes transmit TCP DATA packets to the AP in upstream and the AP transmits TCP ACK packets to the mobile nodes in down-stream. Similar to the UDP experiment, the throughputs of the default DCF method sink rapidly in proportion to the increase of low rate nodes. However, contrary to the upstream UDP experiment, the upstream TCP throughput of the MOAR scheme is poor and similar to that of the default DCF method. This is because TCP is a bidirectional protocol and the throughputs of both directions influence the total TCP performance mutually. In TCP, a TCP ACK packet is generated by successfully transmitted a TCP DATA packet, and the next TCP DATA packet is also generated by successfully transmitted a TCP ACK packet. Thus, in order for a mobile node to transmit multiple TCP DATA packets in a burst for upstream, the AP should transmit multiple TCP ACK packets at once to a mobile node in downstream. However, when we use the MOAR scheme, the AP generally transmits TCP ACK packets one by one to all mobile nodes. This is because the TCP ACK packets from the AP differently head to multiple destinations in downstream. Consequently, a mobile node in the MOAR scheme does not receive multiple TCP ACK packets simultaneously and does not send multiple TCP DATA packets using the burst packet transmission mechanism. As a result, the throughput of the MOAR scheme fails to exceed that of the default DCF method. However, the throughput of the RAT scheme is much better than that of the MOAR scheme and the default DCF method.

This is because the RAT scheme makes it possible for the AP to transmit multiple TCP ACK packets even in multiple destined connections. Therefore, TCP DATA packets are also delivered efficiently using the burst packet transmission mechanism for an upstream TCP traffic environment.



(a) Upstream traffic

(b) Downstream traffic

Fig. 6. System throughput for TCP traffic in infrastructure topology

Fig. 6(b) depicts the system throughputs for the downstream TCP traffic. Similar to the UDP experiment, the throughputs of the default and the MOAR scheme sink rap-idly in proportion to the increase of low rate nodes. However, the RAT scheme shows relatively good throughput in all cases. The total system throughput is slightly de-graded in comparison to that of the UDP case. This is because the TCP ACK consumes a portion of the network resources.

5 Conclusion

In this paper, we proposed a new rate control algorithm, the RAT scheme. The RAT scheme distributes channel resources based on the channel occupancy time. It gives equal time shares to all stations. In addition, the RAT scheme guarantees the channel occupancy time even in a single station by adopting rate-based queue management. As a result, the RAT scheme improves protocol capacity in the face of intra-rate contentions as well as inter-rate contentions.

Through simulations we showed that the RAT scheme is superior to the default DCF method and the MOAR scheme. The RAT scheme displays good performance in all network topologies. Moreover, it uniquely enhances the TCP performance among the compared schemes. In addition, the RAT scheme is practical and easy to implement. This is because the RAT scheme does not require modification of the existing IEEE 802.11 specification. Consequently, the RAT scheme is suitable for multiple rate networks, especially ad-hoc networks where topologies dynamically change.

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