Performance Analysis of Block-ACK Scheme over IEEE 802.11n WLAN

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Abstract. As the most widely used standard of WLAN, IEEE 802.11n leverages data rates at the
physical layer and attempts larger throughput at the MAC (Medium Access Control) layer.
Block-ACK scheme is one of most notable mechanisms to reduce the overhead of ACK frames and
improve channel utilization. However, the common rate adaptation used is still based on the
traditional Imm-ACK (immediate ACK). In this paper, we firstly investigate the problems of applying
Block-ACK scheme to the classical rate adaptation and showed poor performance of these
adaptations. Then we propose the enhancement mechanism for rate adaptation with Block-ACK over
802.11n system which selectively adopts the RTS/CTS mechanism. During the process, we analyze
the impacts of some different important system parameters such as the number of stations. The
simulation results show that the throughput can be improved with the enhanced mechanism.

Introduction

IEEE 802.11n WLAN has gained much attention in industry and research circle for its enormous
adoption and deployment. Aimed at high speed WLAN, the standard introduces the MIMO and
OFDM technology in the PHY layer. Currently, the maximum data rate defined in 802.11 n can reach
up to 300 Mbps. However, the MAC layer's throughput doesn’t increase with higher transmission rate
due to the MAC overhead. In order to reduce the high MAC overhead, a new ACK scheme,
Block-ACK, was introduced. The scheme allows the transmitter to send a group of data frames firstly
and the receiver sends only one ACK frame to acknowledge the group of data frames. Due to the
reduction of the ACK frames, the throughput of MAC layer increases dramatically which is
significant in IEEE 802.11 n where the transmission rate is high.

Rate adaptation plays an important role to the system performance in the wireless networks as a
link-layer mechanism. Although it leverages the throughput by a large scale, it is still unspecified by
the 802.11 standards. The existing rate adaptation works poorly in the IEEE 802.11n systems. What
makes the performance of these rate adaptations in the 802.11n setting different from the legacy
802.11 a/b/g systems is the new technologies introduced in the standard. There are a number of rate
adaptation algorithms for 802.11n proposed in recent years. Their basic ideas focus on the PHY layer
[1, 2]. However, they do not consider the Bloc-ACK scheme in IEEE 80211n. In this paper, we will
extend the work by considering these rate adaptations under the Block-ACK scheme.

The rest of this paper is organized as follows. In Section 2, the Block-ACK mechanism and rate
adaptations are briefly introduced. The problem of rate adaptations under Block-ACK Scheme and
our proposed enhancements are described in Section 3. In Section 4, the Performance of our proposed
enhancements will be given, and finally the conclusions are drawn in Section 5.

The Related Work

Overview of Block-ACK Scheme

To improve the efficiency of MAC layer, IEEE 802.11n uses the Block-ACK scheme combining with
frame aggregation when transmitting data frames. Most of the research work is focused on packet
aggregation [3, 4]. Nevertheless, it has been studied that the large amount of the small-sized control packets can significantly degrade the throughput performance [5]. The Block-ACK scheme reduces the transmission time for preamble and frame headers by sending a BA frame to acknowledge the data block after receiving a number of MPDUs. What’s more, it can also reduce the waiting time during CSMA/CA (Carrier Sense Multiple Access Collision Avoidance) random backoff period for successive frame transmissions.

There are two different types of the Block-ACK mechanism: greedy scheme and the conservative scheme. Both of the approaches use a sequence number (SN) to assign each data frame. The Block-ACK packet will then initiate a bitmap recording the information about the SNs with its first bit starting from a specific starting sequence number (SSN). Once receiving the Block-ACK frame from receiver, the transmitter will be able to decide the correctness of each packet by the bitmap. After that, the conservative scheme will retransmit the failed ones until all the packets are successfully accepted by the receiver. Different from that, the greedy mechanism will combine the failed ones with the new-coming packets and send them to the receiver.

The Rate Adaptation

There have been remarkable studies on rate adaptations in the 802.11 WLANs which are mostly based on the 802.11 a/b/g standard. As the transmitter can adjust rate with or without feedback from the receiver, the rate adaptations can be classified into two categories: open-loop approaches and closed-loop approaches. With the open-loop approaches, the transmitter station adjusts the rate solely based on local acknowledgement information. Therefore, the transmitter station doesn’t need to interact with the receiver station which reduces the complexity of design. On the other hand, these rate adaptation schemes don’t require any change to the current 802.11 standard and hence are compliant with the standard in general. As a result, the open-loop ones attract more attention and gain the most remarkable achievements compared with the closed-loop approaches.

What’s more, the open-loop approaches can be further classified into two subcategories. The first one estimates the status of local channel and chooses the transmission rate on estimation. The rate adaptations in this subcategory often yield high throughput, however, they need extra implementation efforts for the good performance [6, 7]. In contrast, the second subcategory decides the transmission rate using the local ACK information which is simple to implement [8, 9]. The typical rate adaptations in this subcategory e.g. ARF and CARA are widely adopted by the most commercial 802.11n WLAN products, which is the reason we choose them to compare in the simulation.

The Enhanced Rate Adaptation for Block-ACK

Problem of the Rate Adaptation under Block-ACK Scheme

The legacy MAC is based on the DCF (Distributed Coordination Function) with the CSMA/CA. However, the DCF has poor performance due to the MAC overhead and PHY overhead. According to the section 2, the Block-ACK scheme may be a good choice to enhance the throughput by reducing the MAC overhead. As the studies show that the existing rate adaptations perform well under the ACK scheme. But, if these use the Block-ACK scheme, there are some serious problems. In the following, we will present the problems of rate adaptation under Block-ACK scheme in details:

The Problem of the Block-ACK Frame Statistical Issue

As we know, the second subcategory of the open-loop approach uses the local ACK information to choose the transmission rate. As Imm-ACK scheme allows the receiver station to send the ACK frame for each data frame, the rate adaptation can collect the real-time information of data transmission and adjust the rate according to the collected information. Because the threshold for increasing/decreasing the rate is more than one packet, the algorithm will increase/decrease the rate by one time or maintain the current rate after receiving an ACK frame.

However, the BA (Block ACK) frame use a corresponding bitmap to record the information about the reception of the whole block the MPDUs. Based on the scheme, the transmitter will record the
reception of all the MPDUs in the block which leads to the algorithm increasing/decreasing the rate by more than one time. For example, if the Block-ACK shows there are 16 consecutive successfully MPDUS in the block of MPDUS, the ARF will decrease by two times from 54Mbps to 18Mbps. This action will finally result in a large scale rate increment/ decrement and degrade the performance significantly. Therefore, the rate adaptation cannot collect the actual information about the channel and make the appropriate decision. In Fig. 1, we will see that both ARF and CARA have a leapfrog rate increment/decrement under Block-ACK scheme. Here we propose a mechanism to overcome this problem. That is, once a Block-ACK frame is received, the rate adaptation will only decrease by one time even when there are more than two times decrements.

![Graph showing the rate changes of CARA and ARF.](image)

**Figure 1.** The rate changes of CARA and ARF.

The Use of RTS/CTS issue

Since the control frames (RTS, CTS, BACK) are usually transmitted at the basic rate lower than the data rate, the control frames are more robust in combating errors. What’s more, the size of control frames is much smaller than an aggregated data frame which leads to lower frame error rate. Thus, the RTS/CTS access scheme is more efficient than the basic access scheme when transmitting an aggregated data frame. The current transmission sequence will only allow the transmitter to transmit a single data frame when using the RTS/CTS exchange. To solve the problem, IEEE 802.11n specifies a bi-directional data transfer method which allows the receiver to request a reverse data transmission in the CTS control frame. The transmitter can then grant a certain medium time for the receiver on the reverse link. The transmission sequence will then become RTS-CTS-DATAf-DATAR-ACK which is
illustrated in Fig. 2. This method is good for the transmission of some small feedback packets from the receiver and also improves the performance of system.

Nevertheless, most of the traditional rate adaptation doesn’t exchange RTS/CTS frame before transmitting the data frames which reduces the throughput of the rate adaptation. To evaluate the influence of RTS/CTS, we compare the performance of ARF, RTS_ARF and CARA based on simulation. ARF doesn’t initiate the RTS/CTS exchange when transmitting the data frame. On the contrary, RTS_ARF exchanges RTS/CTS frame before every data frame. Based on ARF, CARA initiates the RTS/CTS exchange only when the number of the consecutive failure count reaches the threshold which saves bandwidth efficiently. As we can see in Fig. 3, the throughput of the rate adaptations are CARA highest, followed by RTS_ARF, ARF lowest when the station number n is 4. As for the small number of the transmission stations, initiation RTS/CTS scheme may cause a waste of bandwidth for the low probability of collision. CARA saves the time for sending the RTS/CTS frame and lowers the frame error at the same time, thus, it performs well under Block-ACK scheme. The reason why the throughput of RTS_ARF is quite close to the ARF may be the frequent waste of bandwidth. Different from the small number of transmission stations, the throughput of RTS_ARF is highest, followed by CARA, ARF lowest when n is 20. Due to the strong collision caused by the large number of stations, the RTS/CTS scheme improves the throughput by reducing the collision errors regardless its own cost. Therefore, the throughput of RTS_ARF is much higher than ARF and CARA.

From the above information, the access scheme with RTS/CTS plays an important role in improving and its importance becomes greater with the increasing number of transmission stations. So we propose the enhanced mechanism for the rate adaptation by the adopting RTS/CTS exchange adaptively. Thus, it performs well under Block-ACK scheme. The reason why the throughput of RTS_ARF is quite close to the ARF may be the frequent waste of bandwidth. Different from the small number of transmission stations, the throughput of RTS_ARF is highest, followed by CARA, ARF lowest when n is 20. Due to the strong collision caused by the large number of transmission stations, the RTS/CTS scheme improves the throughput by reducing the collision errors regardless its own cost. Therefore, the throughput of RTS_ARF is much higher than ARF and CARA.

Figure 3. Throughput comparison of CARA, ARF and ARF with RTS/CTS (n=4 or n=20).
From the above information, the RTS/CTS exchange plays an important role in improving throughput and its importance becomes greater with the increasing number of transmission stations. So we propose the enhanced mechanism for the rate adaptation by the adopting RTS/CTS adaptively.

The Problem of Time-Out Data Frame Issue

Based on Imm-ACK scheme, it is believed to be only one missing data packet when the transmitter doesn’t receive the ACK frame after the timer expires. Different from the Imm-ACK scheme, there are a block of MPDUs lost when the transmitter doesn’t receive the BA frame in time. However, the rate adaptation still takes the BA frame as the Imm-ACK frame when it works under the Block-ACK scheme. It makes the rate adaptation make the wrong rate adjustment decision that influences the performance of rate adaptation.

Proposed Enhancements for Rate Adaptation over Block-ACK

According to the above discussion, we propose the following mechanisms to enhance the performance of rate adaptation over Block-ACK scheme.

- Just as ARF, we alternate the transmission rates by keeping track of Block-ACK frame as well as a timing function. After the transmitter receives the BA frame, it detects the last ten SNs of the whole bitmap. Once the SNs indicate there are two consecutive data frames missing, the second retry of the data frame and the subsequent transmissions are done at a lower transmission rate and the transmitter will never count the rest SNs of the BA. On the other hand, if the SNs indicate number of successfully-transmitted data packets reaches 10 or the timer expires, the transmission rate will be raised up to the next higher transmission rate and the timer will be cancelled. Also, the transmitter will never count the rest bits of the BA after the rate is raised. That is to say, the rate will be raised or lowered by only once for each BA frame.
- Once the BA frame is not received for the next frame, the RTS/CTS exchange will be activated.
- When the rate falls back, the condition of the transmission isn’t well and the RTS/CTS scheme will be activated.
- To reduce the frame error rate caused by collision, the RTS/CTS exchange will be activated after the rate is raised for the next block of MPDUs.

Simulation Results

Table 1. NS3 simulation configuration.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Channel</td>
<td>YansWifiChannel</td>
</tr>
<tr>
<td>PHY</td>
<td>YansWifiPhy</td>
</tr>
<tr>
<td>MAC</td>
<td>QosWifiMac</td>
</tr>
<tr>
<td>Remote Station Manager</td>
<td>ArfWifiManager</td>
</tr>
<tr>
<td>Data Mode</td>
<td>OfdmRate</td>
</tr>
<tr>
<td>Block ACK threshold</td>
<td>1</td>
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<tr>
<td>Mobility model</td>
<td>ConstantPosition</td>
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<tr>
<td>IP Address</td>
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<tr>
<td>Socket</td>
<td>UdpSocketFactory</td>
</tr>
<tr>
<td>Application</td>
<td>OnoffApplication</td>
</tr>
<tr>
<td>Data transmission rate</td>
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</tr>
<tr>
<td>Slot time</td>
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</tr>
<tr>
<td>Propagation delay</td>
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</tr>
</tbody>
</table>

To show potential of our proposed mechanism, we perform the simulations based on the simulation environment using the ns-3 network simulator. Some specific MAC and PHY parameters are listed in the Table 1 and the configuration information of the simulation is listed in the Table 1. In order to make the data rate up to 54Mbps, we set the default PHY configuration as YansWifiChannel and YansWifiPhy proposed by M.Lacage et al. At the same time, we use the QosWifiMac model proposed
by M. Banchi as the MAC configuration which has four ACs and each AC has set the CW_{min} and CW_{max}. All the data packets passed down to the MAC layer are 1500 Bytes in length. The number of packets aggregated in one MAC frame varies from 1 to 64, which leads to an aggregated payload size from 1.5Bytes to 96KBytes.

![Figure 4. Throughput comparison of our proposal (Enhanced CARA) against CARA and ARF (n=4).](image)

First, we compare the performance of our enhanced rate adaptation with CARA and ARF under Block-ACK scheme. Fig. 4 illustrates the throughput of these rate adaptations and all the lines are the results obtained from the simulation in the case that n=4. We can see that the throughput of our proposed rate adaptation is larger than the other two. The Fig. 5 illustrates that the throughput gain is mainly due to the progressive increase and decrease of the rate. As Fig. 5 shows, ARF and CARA always have a leapfrog rate increase and decrease during transmission such as directly decreasing from 54Mbps to 6Mbps. Different from that, our improved rate adaptation always have a slow change in the rate which attempts to transmit the data frame with the highest transmission rate. Thus, it can maintain the higher transmission rate than ARF and CARA which leads to a significantly increased throughput.

![Figure 5. The rate changes of our proposal (Enhanced CARA) against CARA and ARF (n=4).](image)
Next, let us discuss the impact of some parameters on the performance of rate adaptation. As we
know, 802.11n adopts two different kinds of modulation, namely, BPSK (Binary Phase shift Keying)
and QAM (Quadrature Amplitude Modulation). The probability of these modulation are different as
shown in Eq. 1 and Eq. 2, the former one is the loss probability of BPSK $P_{bpsk}$ and the other is the loss
probability of QAM $P_{qam}$. When the physical rate changes, it will turn to different modulation mode
leading to the different loss probability. So, it’s difficult to measure the impact of the loss probability
on the rate adaptation.

$$
P_{bpsk} = \frac{1}{2} erfc\left(\sqrt{\frac{snr}{2\sigma^2}}\right)$$

$$
P_{qam} = \frac{1}{2} erfc\left(\sqrt{\frac{snr \cdot \text{signalspread}}{2\text{phyrate}}\cdot\frac{1.5 \cdot \log_2 (m) \cdot \text{signalspread}}{\text{phyrate} \cdot \log_2 (m) - 1}}\right)
$$

As mentioned before, the enhanced rate adaptation has a high throughput when the station size $n$ is
small. Obviously, the parameter $n$ plays an important role on the performance. The results of the
throughput vs. $n$ are shown in Fig. 6.

In this figure, we can see that in the two scenarios, the throughput becomes smaller with the
increasing of $n$. From this figure, the throughput of enhanced rate adaptation is always larger than that
of CARA. It can be conclude that the rate adaptation perform well compared with CARA.

Conclusion

In this paper, we studied the performance of rate adaptation under Block-ACK scheme in IEEE
802.11n system. It is observed that the rate adaptation does not achieve a satisfied performance due to
some problems which is verified in our simulation. Based on these observations, we proposed some
enhancement schemes to improve the performance. The throughput of the enhanced rate adaptation is
larger than the others. We also studied some parameter on the performance of rate adaptation.
Acknowledgement

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References


