Resolving Collisions in IEEE 802.11 by means of Contention Window Reservation Scheduling

Hushairi Zen and Daryoush Habibi, Senior Member, IEEE
School of Engineering
Edith Cowan University
Joondalup, WA 6027
Australia
Email:hzen@student.ecu.edu.au

Abstract—The random backoff contention window algorithm implemented in the IEEE 802.11 Distributed Coordination Function (DCF) provides a certain degree of collision mitigation. However, the issue of high collision rates within the IEEE 802.11 contention mode in a wireless local area network (WLAN) with high number of nodes is still not resolved. High packet collision rates result in throughput degradation and increased delay and thus unable to support QoS for multimedia traffic. In this paper, we propose a Contention Window Reservation Scheduling (CWRS) algorithm to resolve packet collisions in the contention mode of 802.11 WLANs. Through proper scheduling, this algorithm provides collision free transmission and optimized throughput. Within the proposed algorithm, saturation throughput increases by more than 30% when there are more than 20 nodes in the network and medium access delay is also reduced by up to 90% as compared to 802.11. This enables WLAN to support QoS for multimedia traffic.

I. INTRODUCTION

In a WLAN, nodes communicate through a shared wireless channel. When multiple nodes try to transmit packets on a shared communication channel, collisions can occur. To avoid collisions, an effective medium access mechanism is needed, which controls and manages access to the shared channel. The most popular medium access mechanism used in wireless LANs is currently the IEEE 802.11b which is also known as the legacy IEEE 802.11 [1] MAC protocol. However, this protocol was designed for data communication and does not provide satisfactory services for real-time traffic [2]. It adopts the carrier sense mechanism of the Ethernet and implements it in WLANs with minor changes to avoid collisions. Although this protocol is robust, it is not well optimised. Packet loss and delay due to packet collisions is high.

To enhance the legacy IEEE 802.11 protocol, the IEEE 802.11e MAC protocol was introduced. The 802.11e provides prioritization of real-time traffic and improves quality of service (QoS) [3]. However, both the legacy and the enhancement protocol adopt the random binary exponential backoff mechanism to avoid packet collisions. This mechanism successfully reduces collisions but as the number of nodes in the network increases, rate of packet collisions also increases. As a result of packet collision, network performance degrades and QoS deteriorates. Lost packets due to packet collisions need to be resent and contention window backoff values are doubled.

There have been several schemes proposed to mitigate collisions in WLAN contention mode [4][5]. Although an improvement over the legacy 802.11 is shown in these schemes, most benefits are limited due to increase overhead as a result of adding extra information in the MAC header. In [5], early backoff announcement is implemented where a station announces its future backoff information to avoid collisions. This information needs to be broadcast to all wireless nodes, and thus must be added into the MAC header. Alternatively, in [4] a multiple input-output approach is adopted, whereby an access point (AP) needs to have more than one receiving antenna, which in turn increases complexity at the physical layer.

In this paper, we propose a contention window reservation scheduling (CWRS) mechanism that resolves collisions in WLAN. In this mechanism, the contention window is scheduled so that no wireless node has the same contention window value at the same instance. We show that with this mechanism, it is possible to achieve collision free transmission in the wireless contention mode which results in higher throughput and significantly lower packet delay. The proposed mechanism also provides easy migration from the legacy 802.11 as changes only involve the backoff mechanism and other parameters of this protocol remain unchanged.

II. THE LEGACY 802.11 CONTENTION WINDOW ALGORITHM

In the legacy 802.11, if the medium is sensed to be busy, the node must wait a random period of time before attempting to access the medium again. This reduces the probability that multiple stations wishing to send data transmit at the same time. In the exponential backoff scheme adopted by the DCF, a backoff timer is uniformly chosen in the range \(0, CW - 1\) after each successful packet transmission. Initially, \(CW\) is set to \(CW_{min}\), the minimum value allowable for the contention window. After each unsuccessful transmission, \(CW\) is doubled, up to a maximum value of \(CW_{max} = 2^m CW_{min}\). The values \(CW_{min}\) and \(CW_{max}\) are 32 and 1024 respectively for Frequency Hopping Spread Spectrum (FHSS) modulation [6].
a collision free transmission.

works well and manages to mitigate packet collisions with low contention until the backoff timer reaches zero. This mechanism can be achieved by the following algorithm: after sensing that the channel is idle for a period of DCF interframe space, all nodes will occupy a different contention window slot, which is set to a fixed value, \( CW_n \) while in the legacy 802.11 the contentation window is randomly set to any contention window slot from \( 0 - CW_{31} \). While at this point, node that has \( CW_2 \) will have reduced it to \( CW_1 \) and be ready to transmit after a DIFS and a slot decrease. This procedure will ensure that no two nodes occupy the same slot, thereby avoiding packet collisions. Following this, a node that is in a state where its contention window is at \( CW_1 \) will gain access to the channel after the next idle period of a DIFS plus a slot decrease. This mechanism eliminates packet collisions in nodes already in the network.

However, a node new to the network that wants to access the channel must transmit a broadcast packet to inform all the nodes in the network. This new node is given a privilege to transmit over other nodes by having \( CW_0 \). This means that a new node can transmit its admission broadcast packet after an idle period of a DIFS. After completing its transmission, it then sets its \( CW \) to \( CW_n \). All other nodes then decrease their \( CW \) by one. A node which has \( CW = 1 \) will decrease its contention window slot by one to \( CW_0 \) and be ready to transmit after the next DIFS idle period. By giving \( CW_0 \) to the new node, the scheduled contention window mechanism avoids the broadcast packet of a new node colliding with packet of a node ready to transmit, and also avoids delay to admission of new nodes. The probability of more than one new node attempting to get admission at the same time, after the same DIFS period elapses and therefore causing collision is very small. This is because the duration from a DIFS to the next DIFS period is not more than one second, even with low bit rate and long packet length. However, if two nodes are trying to get admission at the same time after a DIFS, both the nodes will occupy \( CW_n \). This will cause collision when the \( CW \) of both the nodes reaches 0 at the same time. To resolve this problem, both nodes need to do virtual random backoff after their broadcast packets collided. The node that has lower value of backoff will win the contention and access the channel after a DIFS to broadcast its initial packet. When this node has completed transmission, it then has its \( CW \) set to \( CW_n \).

The broadcast packet of a node new to the network is very important for two reasons; firstly, it informs all other nodes in the network of its presence, and secondly, it allows the new node to get information on the contention window slots that have already been occupied. This information is also used for other nodes to update their schedule table and for the new node to track the contention window positions of other nodes in the network. Two different scenarios could take place when nodes in the network receive the packet broadcast by the new node. In infrastructure WLAN, where the access point (AP) is present, the AP replies to the broadcast packet with the information containing the positions of the occupied contention window slots. In the absence of the AP such as in an ad-hoc network, the node with the contention window \( CW_1 \) replies after a Short Interframe Space (SIFS) with the information. This avoids multiple replies and prevents collision. If the node with position \( CW_1 \) replies, it does not
Nodes which are already in the network follow the scheduled contention window and transmit packets without collisions. We make a comparison of our model against the IEEE 802.11b shown in [9] and [10] and show that the performance of our algorithm is significantly better.

First, consider a single node transmission in basic transmission mode without using a Request-to-send/Clear-to-send (RTS/CTS) algorithm. The time taken to transmit a data frame from the instant the node hears the channel idle is:

\[ T_{\text{data}} = \text{DIFS} + \sigma + \frac{L_{\text{data}}}{R_{\text{data}}} + T_{\text{phy}} + \delta \]  

(1)

where

- \( T_{\text{data}} \) — Time taken to transmit a data frame
- \( L_{\text{data}} \) — Length of data frame (Payload + Mac Header)
- \( R_{\text{data}} \) — Physical layer data rate
- \( T_{\text{phy}} \) — Time taken to transmit a Physical header (PLCP Preamble + header)
- \( \sigma \) — Duration of a slot time
- \( \delta \) — Propagation delay

The time taken for the receiving node to make an acknowledgment is:

\[ T_{\text{ack}} = \text{SIFS} + \frac{L_{\text{ack}}}{R_{\text{basic}}} + \delta \]

(2)

where

- \( T_{\text{ack}} \) — Time taken to transmit acknowledgment packet
- \( L_{\text{ack}} \) — Length of acknowledgment packet
- \( R_{\text{basic}} \) — Physical layer basic rate

For a receiving node that is waiting to send acknowledgment to the transmitting node, and having a data frame to be sent to the same node, the frame can be sent after a SIFS. By receiving this frame, the node is aware that the last frame it sent was successful.

From equations 1 and 2 the time taken for a cycle of DIFS are given as:

\[ T_{\text{data+ack}} = \text{DIFS} + \sigma + \frac{L_{\text{data}}}{R_{\text{data}}} + T_{\text{phy}} + 2\delta + \text{SIFS} + \frac{L_{\text{ack}}}{R_{\text{basic}}} \]

(3)

and

\[ T_{\text{data+ack+data}} = \text{DIFS} + \sigma + 2\left(\frac{L_{\text{data}}}{R_{\text{data}}}\right) + T_{\text{phy}} + 2\delta + \text{SIFS} \]

(4)

for node replying without data and with data respectively.

Therefore, for \( n \) number of nodes, the times taken for a cycle of DIFS for nodes without data and with data are:

\[ (T_{\text{data}} + T_{\text{ack}})n \]

(5)

and

\[ (T_{\text{data}} + T_{\text{ack+data}})n \]

(6)
A. System Throughput

The network total saturation throughput, $S$, is defined as a ratio of successfully transmitted payload size over time slot duration:

$$ S = \frac{E[P]}{E[T]} $$  \hspace{1cm} (7)

where, $E[P]$ is the value of the successfully transmitted data payload sizes, and $E[T]$ is the corresponding expected value of time slot duration and is expressed as:

$$ E[T] = T_{data} + T_{ack} + (T_{data} \times P_{data-err}) + (T_{ack} \times P_{ack-err}) $$  \hspace{1cm} (8)

where, $P_{data-err}$ and $P_{ack-err}$ are the probabilities of data frame and acknowledgment frame respectively being received as corrupted.

The probability of corrupted data in the wireless medium has been widely researched. Given that bit errors are uniformly distributed over the whole frame, $P_{data-err}$ and $P_{ack-err}$ can be calculated as:

$$ P_{data-err} = 1 - (1 - p_b)^{L_{data}} $$  \hspace{1cm} (9)

$$ P_{ack-err} = 1 - (1 - p_b)^{L_{ack}} $$  \hspace{1cm} (10)

where $p_b$ is bit error rate and can be estimated by measuring the bit-energy-to-noise ratio.

For Binary Phase Shift Keying (BPS) and Quadrature Phase Shift Keying (QPSK) modulations, the bit error rate can be calculated as:

$$ p_b = Q(\sqrt{\frac{E_b}{N_0}}) $$  \hspace{1cm} (11)

and for M-array Quadrature Amplitude Modulation (QAM), $p_b$ can be calculated as follows [2]:

$$ p_b = 4(1 - \frac{1}{\sqrt{M}})Q(\sqrt{\frac{3E_b}{(M - 1)N_0}}) $$  \hspace{1cm} (12)

where $E_b$ is the bit energy-to-noise ratio of the received signal and Q-function is defined as:

$$ Q(x) = \int_{x}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt $$  \hspace{1cm} (13)

The system throughput can now be modelled as:

$$ S = \frac{P_S L_{pld}}{T_{data} + T_{ack} + (T_{data} \times P_{data-err}) + (T_{ack} \times P_{ack-err})} $$  \hspace{1cm} (14)

where $P_S$ is the probability of a collision free transmission.

As there is no collisions in the scheduled contention window, $P_S = 1$. As the nodes in the network are assumed to be in saturation, it can be shown that the system throughput is independent of the number of nodes as shown in (14).

Using the Frequency Hopping Spread Spectrum (FHSS) parameters as shown in Table I, we show the saturation throughput of our proposed scheduled contention window algorithm as compared to the IEEE 802.11b random backoff contention window algorithm. In Figure 3, it can be seen that the saturation throughput of our CWRS outperforms the IEEE 802.11b. As the number of nodes is increased, performance of the IEEE 802.11b drops while the performance of our CWRS is sustained. This is due to increase in packet collisions and contention window sizes in the IEEE 802.11b, while in our CWRS; packets are transmitted every cycle only after the DIFS period. Throughput is therefore sustained at the same level, irrespective of the number of nodes in the network. The IEEE 802.11b uses a maximum data rate of 11 Mbps while recommends a basic rate of 1 Mbps. We adopt this rate and the saturation throughput model is shown in Figure 4 for payload sizes of 120, 500 and 1200 bytes.

<table>
<thead>
<tr>
<th>Table I</th>
<th>FHSS System Parameters and Other Physical Layer Parameters Used to Obtain Numerical Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC header</td>
<td>272 bits</td>
</tr>
<tr>
<td>PHY header</td>
<td>144 bits</td>
</tr>
<tr>
<td>ACK</td>
<td>112 bits + PHY header</td>
</tr>
<tr>
<td>Channel Bit Rate</td>
<td>11 Mbps</td>
</tr>
<tr>
<td>Propagation delay</td>
<td>2 μs</td>
</tr>
<tr>
<td>Slot Time</td>
<td>20 μs</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 μs</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 μs</td>
</tr>
</tbody>
</table>

Figure 3. Saturation throughput of scheduled CW and the legacy 802.11b with data rate and basic rate of 11 Mbps

Figure 4. System throughput of scheduled CW and legacy 802.11b with data rate of 11 Mbps and basic rate of 1 Mbps
B. Average Packet Medium Access Control (MAC) Delay

Packet Medium Access Control (MAC) delay is defined as the time that elapses after a packet has been successfully transmitted to the time of the next consecutive successful transmitted packet on the same traffic stream. This delay depends on several factors, the number of nodes in the network, the size of the data packet and the data rate. This delay can be shown with the following derivation:-

The time taken for transmitting a packet and receiving an acknowledgment is given in (3). Using (3) we can deduce the time delay for a node to send a consecutive packet as:-

\[ T_{delay} = T_{data+ack} \times n \]  

(15)

where, \( T_{delay} \) is the MAC access packet delay for each stream and \( n \) is the number of nodes in the network.

Figure 5 shows the average MAC access packet delay against the number of nodes in the WLAN network. A data rate of 11 Mbps and basic rate of 1 Mbps are used in this model. The analytical modelling of the IEEE 802.11b DCF protocol is validated using NS simulation software [12]. It can be seen that the average delay of the CWRS is significantly lower than the IEEE 802.11b DCF. For a packet size of 1200 bytes the average delay experienced by the CWRS with 30 nodes in the network is less than 40 ms, while in the IEEE 802.11b DCF, it is about 370 ms. This significant reduction in packet delay in the proposed CWRS shows that this algorithm is able to support QoS for real-time traffic.

V. Conclusion

In this paper we have presented an effective mechanism to resolve packet collisions in the contention mode of 802.11 WLANs. Based on the contention window reservation scheduling (CWRS) mechanism, each traffic stream is scheduled to a specific contention window. As nodes transmit in a scheduled manner, only one node is allowed to transmit packets at any given time, which results in collision free transmission. It is shown that with this mechanism, the saturation throughput of WLANs is significantly higher as compared with the random backoff mechanism employed in the IEEE 802.11b. The average MAC access packet delay is also reduced by up to 90% compared with the IEEE 802.11b DCF. The contention window reservation scheduling scheme provides strict channel access control, resulting in a tight delay bound which makes it a good candidate for QoS provisioning to applications with stringent QoS requirements such voice and video traffic in multimedia applications.

Our proposed CWRS mechanism has shown that medium access can be optimised by providing collision free transmission and eliminating overhead delay due to empty contention window slots. This scheme has the potential to resolve many drawbacks of the 802.11 standard in providing QoS for multimedia traffic. As almost all other parameters of 802.11 are retained, migration from random backoff to the backoff scheme in our proposed mechanism can be easily achieved. Although this scheme has shown to be very promising in providing QoS for real-time traffic and optimising network performances, more work is needed to ensure that it works well in all WLAN environments carrying multimedia applications. Our future work will include non-saturation network environment, integrating prioritization of real-time traffic, defining payload size for each transmission and designing a multi-queuing functionality within this mechanism.

REFERENCES