Overhead reduction in rate-adaptive MAC over OFDM-based wireless networks

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While many researchers have focused on bit-loading algorithm itself, proposed here is an implementation method of the bit-allocation in terms of layer-2 protocol. A novel protocol is presented to implement a bit-allocation over time-varying wireless channels by using as small an overhead as only one OFDM symbol.

Introduction: Conventional rate-adaptive OFDM-based wireless systems use a fixed constellation size and power level over all subcarriers, as in the case of the IEEE 802.11a standard [1–3]. However, this is inefficient over frequency selective fading channels. To cope with the frequency selective channel condition as well as to achieve efficient rate adaptation, applying a different constellation size (or number of bits or data rate) to each subcarrier according to its channel condition provides more reliable and efficient data transmission. To implement this, a communication pair needs to exchange information of all subchannels, and this information overhead becomes large. In addition to the large amount of information to be exchanged, time-varying wireless channels require frequent exchanges of that information, that is, the overhead is a key obstacle to implement bit-loading schemes over wireless. While much research has been done for the bit-loading algorithm itself [4–6], little effort has been made to design an efficient protocol to achieve such bit-loading algorithms over wireless networks. In [7], only the strongest subcarriers are used with high-order constellation. The receiver informs the sender which subcarriers will be used for the next data transmission. Even though the feedback overhead is reduced to two OFDM symbols, the method in [7] cannot fully utilise all the subcarriers. In addition, some of the chosen subcarriers may not be strong enough to deal with the high-order constellation. We propose a novel protocol, which not only uses a small overhead, but also is able to utilise entire subcarriers to implement a rate adaptation over the wireless networks.

Protocol description: We propose the use of a bitmap over an IEEE 802.11-based protocol. The bitmap is a table, recording and indicating how many bits were or are allocated to each subcarrier of OFDM symbols in a previous or current data packet. The bitmap is located in the internal memory of each station. Each station generates a bitmap when a communication is initiated, and it maintains the bitmap for each communication pair. The bitmaps of a communication pair, namely a transmitter and a receiver, have to be synchronised with each other. Since the number of bits is directly proportional to the data rate of each subcarrier (data rate = number of bits/OFDM symbol duration), hereinafter we use only the data rate to avoid confusion.

In this proposed protocol, the packet formats of the CTS and PLCP header in the data are manipulated as shown in Fig. 1. The 'rate' subfield in the CTS PLCP header of IEEE 802.11a is changed to a bitmap-flag subfield to indicate the use of the bitmap. When the bitmap-flag subfield is set to 1111, a 'bitmap-adjustment' OFDM symbol is inserted between the PLCP header and MPDU. A bitmap-flag with the value 0000 indicates that the bit allocation is not changed, so that no 'bitmap-adjustment' follows after the PLCP header.

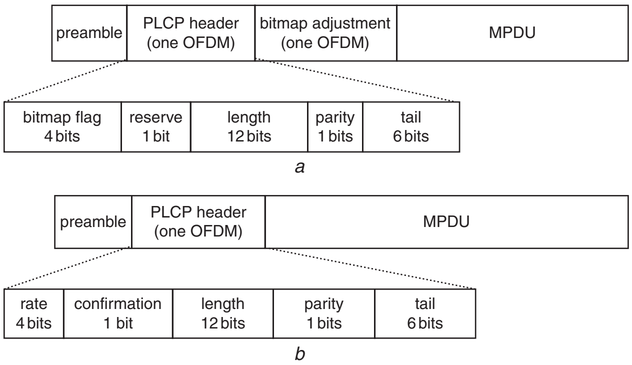


Fig. 1 *Packet structures*

a CTS packet with bitmap-adjustment OFDM symbol
b Data packet

The 'bitmap-adjustment' OFDM symbol is composed of 48 data subcarriers and four parity subcarriers. Each subcarrier includes one of the BPSK symbols. This additional OFDM symbol is used to adjust the data rate allocated to the subcarriers for the subsequent data transmission.

For a data packet, only one subfield is changed, as shown in Fig. 1*b*. The 'reserved' subfield in the data PLCP header in IEEE 802.11a is used as a 'confirmation' subfield.

Protocol operation: The process to update the data rate of each subcarrier for a subsequent data transmission is as follows:

Step 1: A receiver estimates the conditions of all the subcarriers (e.g. signal-to-noise ratio (SNR)) from the received RTS packet and chooses the data rates suitable for their conditions. We assume that the data rate is selected based on a predetermined threshold [1–3].

Step 2: The chosen data rates for the subcarriers are compared to the data rates in the current bitmap. After comparison, the receiver chooses one of the three actions: to increase, to decrease and not to change the data rate on each subcarrier for the subsequent data frame.

Step 3: According to the decision in step 2, the receiver sets 1 to increase or −1 to decrease the data rate on each subcarrier in the bitmap-adjustment symbol. If the decision of a subcarrier is not to change, then the receiver sets a different value from the value used in the same subcarrier of the previous CTS.

Step 4: Once the values on the 'bitmap-adjustment' symbol are decided, the actual data rate for upcoming data transmission is selected according to Table 1, which illustrates how to choose data rate based on the values on both the current and the previous CTS bitmap-adjustment OFDM symbols. Then, the bitmap is updated with currently chosen data rates.

Step 5: The receiver sends the CTS packet to the source (i.e. a sender of RTS packets), including a 'bitmap-adjustment' OFDM symbol.

Step 6: Receiving the CTS packet, the source also updates its bitmap following the rule shown in Table 1.

Step 7: By using the data rates represented in the updated bitmap, the source generates and sends a data packet with the 'confirmation' subfield set to 1.

Step 8: When the destination receives the data packet with the 'confirmation' subfield set to 1, it demodulates the packet based on the bitmap information and sends an ACK to the source.

Step 9: If the source fails to receive an ACK packet after the data packet transmission, it changes the current data rate information to the previous information contained in its previous bitmap and retransmits an RTS.

Step 10: When the receiver receives an RTS with a non-zero retry bit (implying retransmission), it changes the current data rate information to the previous information contained in its previous bitmap.

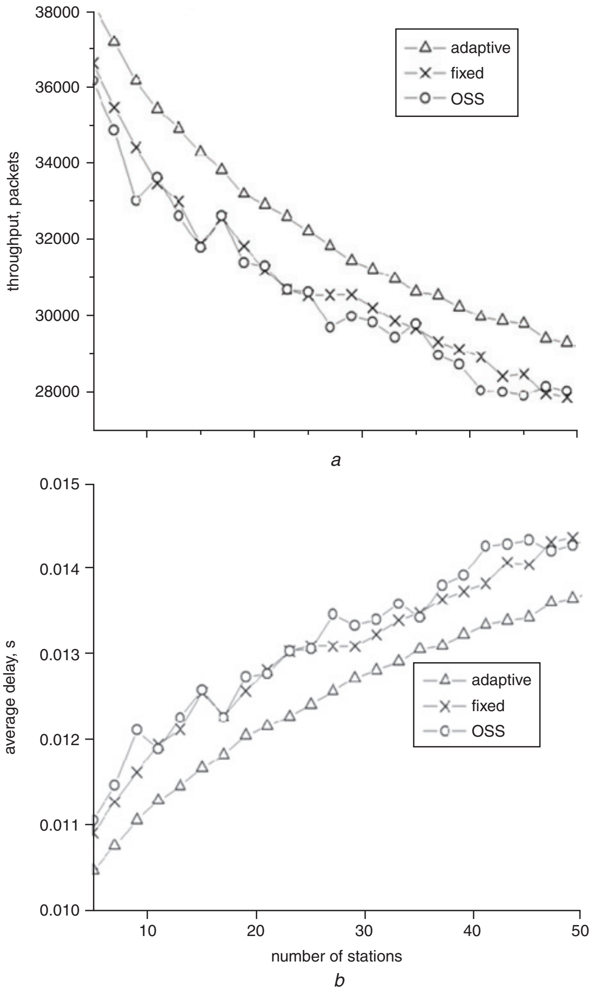
Step 11: If the reception of the data packet at the receiver fails for any reason (e.g. channel error or collision), the receiver changes the current data rate information to the previous information contained in the bitmap. In this case, since an ACK will not be sent, the source also changes the current data rate information to the previous information contained in its bitmap.

Step 12: If the transmission of the CTS packet fails, the destination goes back to the previous bit allocation information contained in the bitmap, as in the case of data packet loss.

Table 1: Data rate adjustment on each subcarrier according to symbols assigned in bitmap-adjustment OFDM symbols

Symbol on subcarrier in previous bitmap-adjustment OFDM symbol	Symbol on subcarrier in current bitmap-adjustment OFDM symbol	Data rate adjustment in bitmap
−1	−1	Decrease one level from previous data rate
−1	1	Do not change
1	−1	Do not change
1	1	Increase one level from previous data rate

Performance evaluation: A centralised WLAN system with one access point (AP) and N stations is simulated over a Ricean fading channel model with Ricean parameter 10. The PHY layer has eight PHY modes defined in the IEEE 802.11a standard. All the stations except for the AP are randomly distributed in a circular area with a diameter of 100 m and move randomly at a pedestrian speed. The AP is located at the centre of the area. The traffic load is saturated in each station. The packet size is 1024 bytes. For the purpose of evaluation, the proposed method, called ‘adaptive’, is compared with ‘OSS’ proposed in [7] and ‘fixed’ described in [2, 3]. ‘Fixed’ changes the data rate based on the channel, but uses the same PHY mode over all subcarriers. ‘Fixed’ loads a data rate for a subcarrier having the worst channel condition on all subcarriers. While all three methods use the RTS/CTS/DATA/ACK handshaking in the IEEE 802.11 standard, our method uses the proposed CTS and data packet formats shown in Fig. 1. Although it might need two or more OFDM symbols, we assume that OSS also uses one OFDM symbol for the feedback of the subcarrier information. In OSS, only the selected strong subcarriers are used for packet transmission as described in [7]. The value of −65 dBm is selected as the threshold level for OSS because this level provides the best throughput performance among the other eight levels according to the simulation. Fig. 2 shows the performance improvements of the proposed method in throughput and delay perspective. The proposed method, ‘adaptive’, provides an improvement in the throughput of up to 8% compared to ‘fixed’ and 11% compared to ‘OSS’. In addition, the proposed method reduces average delay up to 8.5 and 10.5% compared to ‘fixed’ and ‘OSS’, respectively.



a

b

Fig. 2 *Simulation results*

a Throughput against number of stations
b Average packet delay against number of stations

Conclusions: The proposed protocol resolves a key obstacle, i.e. large subcarrier state feedback information, to implementing subcarrier-wise rate adaptation over wireless networks. By adding only one OFDM symbol to the conventional protocol and utilising it, it enables complete subchannel-wise rate adaptation to be implemented. In addition, the proposed method shows performance improvements of wireless networks over frequency selective fading channels.

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