Computer Standards & Interfaces 44 (2016) 144–149

Contents lists available at ScienceDirect

Computer Standards & Interfaces

journal homepage: www.elsevier.com/locate/csi

The performance evaluation of IEEE 802.11 DCF using Markov chain model for wireless LANs

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ARTICLE INFO

Article history:
Received 1 February 2015
Received in revised form 29 July 2015
Accepted 2 September 2015
Available online 8 September 2015

Keywords:
Wireless local area networks
DCF
RTS/CTS
Access mechanisms

ABSTRACT

During the past few years the widespread use of the wireless local area networks (WLANs) communication technique is one of the most popular technologies in data telecommunications and networking. The IEEE 802.11 protocol has achieved worldwide acceptance with WLANs with minimum management and maintenance costs. The theoretical performance and numerical results in terms of saturation throughput and delay of distributed coordination function (DCF) were finished by Ziouva and Antonakopoulous. It took into account of the busy medium conditions and how they affected the use of the backoff mechanism. However, the definition of their proposed channel busy probability is not suitable for the operating system architecture. In this paper, the channel busy conditions is modified and the Ziouva and Antonakopoulous's (ZA's) model is improved, and the more accurate analyses of the DCF are presented. Our analysis is also extended to the computation of the delay performance of both the request-to-send/clear-to-send (RTS/CTS) and basic access mechanisms. The numerical results show that the modified model has better performance than the ZA's model under ideal channel scenario.
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1. Introduction

In recent years, the wireless local area networks (WLANs) market is experiencing an explosive growth. The medium access control (MAC) protocol is the key element that provides the efficiency in accessing the channel, while satisfying the QoS requirements.

The IEEE 802.11 wireless local area network is a shared-medium communication network that transmits information over wireless links for all IEEE 802.11 stations in its transmission range to receive. It is one of the most deployed wireless networks in the world and is likely to play a major role in multimedia home networks and next-generation wireless communications. IEEE 802.11 wireless networks can be configured into two different modes: ad hoc and infrastructure. In the ad hoc mode, all wireless stations within the communication range can communicate directly with each other, whereas in the infrastructure mode, an access point (AP) is needed to connect all stations to a distribution system (DS), and each station can communicate with others through the AP. IEEE 802.11 is composed of both a physical layer (PHY) and MAC specifications for wireless local area networks [1,2].

In the IEEE 802.11 protocol, the fundamental mechanism to access the medium is called the distributed coordination function (DCF). This is a random access scheme which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. The standard also defines an optional point coordination function (PCF) which is based on a polled-response mechanism.

In the DCF, if a station has a frame to transmit, it will monitor the channel. If the channel is busy, the MAC waits until the medium becomes idle, and then defers for an extra time interval, called the DCF Inter-frame Space (DIFS). After sensing the channel within a DIFS, the station (STA) randomly chooses a backoff interval before transmitting. The backoff counter is decremented in terms of a time slot as long as the channel is sensed as being idle. The counter is stopped when a transmission with other STAs is detected on the channel and reactivated when the channel is sensed as being idle again for more than a DIFS. The station transmits its frame when the backoff counter reaches zero. At each transmission, the backoff time is uniformly chosen in the range $[0, W-1]$, where W is the current backoff window size. W equals the initial backoff window size CW_{min}. After each unsuccessful transmission, W is doubled until a maximum backoff window size value CW_{max} is reached. Once it reaches CW_{max}, W shall remain at the value CW_{max} until it is reset. W shall be reset to CW_{min} after every successful transmission or the retransmission counter reaches the retry limit (L). After the destination station successfully receives the frame, it transmits an acknowledgment frame (ACK) following a short inter-frame space (SIFS) time. If the transmitting station does not receive the ACK within a specified ACK timeout or it detects the transmission of a different frame on the channel, it reschedules the frame transmission according to the previous

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http://dx.doi.org/10.1016/j.csi.2015.09.002
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backoff rules. The above mechanism is called the basic access mechanism (ACK CSMA/CA) as shown in Fig. 1. To reduce the hidden station problem, an optional four-way handshakes data transmission mechanism called request-to-send (RTS)/clear-to-send (CTS) as shown in Fig. 2 is also defined in the DCF. Before transmitting a packet, a station operating in a RTS/CTS mode "reserves" the channel by sending a special request-to-send short frame. The destination station acknowledges the receipt of a RTS frame by sending back a clear-to-send frame. Since collision may occur only on the RTS frame, and if it is detected by the lack of a CTS response, the RTS/CTS mechanism allows for an increase in the system performance by reducing the duration of a collision when long messages are transmitted [1–3].

There have been many performance analyses of the IEEE 802.11. Bianchi [2] proposed a simple and accurate analytic model to the computer saturation throughput. Ziouva and Antonakopoulous [4] improved Bianchi's model to derive a saturation delay. Wu et al. [5] improved Bianhi's model to consider a retry limit. Hadzi-Velkov and Spasenovski [6] improved Bianchi's model to consider a retry limit in the fading channel. In real-time applications such as voice and video, the SAT might take an arbitrarily long time to access the channel.

The rest of this paper is organized as follows. In Section 2 a general description of our proposed model is presented. Analytical performance deviations of modified model with RTS/CTS and basic access mechanisms including throughput and delay analysis are presented in Section 3. The numerical results are given with discussion in Section 4. Finally, conclusions are drawn in Section 5.

2. Overview of the modified DCF model

In the CSMA/CA protocol, the STA has a frame to transmit. It must sense the channel. If the channel is idle for a period of time equal to a distributed inter-frame space (DIFS), the station transmits. Otherwise, if the channel is sensed busy (either immediately or during the DIFS), the station has to wait for an additional DIFS, and generate a random delay (backoff process) before transmitting its frame. The delay is uniformly chosen in the range $(0, W-1)$, which is called a contention window. When a STA finishes the backoff process and the medium has been idle longer than the DIFS time interval, the frame is transmitted immediately. If there are transmissions from other STAs during this time period, the STA will double up the contention window and enter the next stage, otherwise the STA will enter the $\{-1, 0\}$ state. The STA will freeze its backoff counter until the end of the transmission as there are transmissions from other STAs during this time period. Then, the STA resumes its counter after the DIFS. At the first transmission attempt, W is set to be equal to a value $CW_{\min}$, called the minimum contention window. After each unsuccessful transmission, W is doubled up to a maximum value $CW_{\max} = 2^m CW_{\min}$. The backoff time counter is decremented as long as the channel is sensed idle, "frozen" when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than a DIFS. The station transmits when the backoff time reaches zero.

Since a collision cannot be detected in the CSMA/CA protocol, there are two mechanisms to determine the successful reception of a frame. The first one is called the ACK CSMA/CA mechanism. For each successful reception of a frame, the receiving station immediately acknowledges receipt by sending an acknowledgement (ACK) frame. The ACK frame is transmitted after a short IFS (SIFS), which is shorter than the DIFS. Other stations resume the backoff process after a DIFS time. If an ACK frame is not received after the data transmission, the frame is retransmitted after another backoff process.

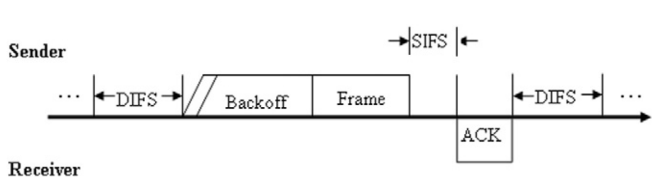

Fig. 1. ACK CSMA/CA in DCF.

The second mechanism is called the RTS/CTS CSMA/CA mechanism. The STA that wants to transmit a frame follows the backoff process. It transmits an RTS frame instead to the receiving STA. When the receiving STA detects an RTS frame, it responds, after a SIFS, with a CTS frame. The transmitting STA is allowed to transmit its data frame only if the CTS frame is correctly received. The RTS/CTS frames are short frames and carry the information about the length of the data frame to be transmitted. Thus, a hidden station will avoid collision by detecting just either the RTS or CTS frame. The RTS/CTS mechanism is very effective when large size data frames are considered [4].

We used some similar procedures and index in [4]: $b(t)$ is defined as a stochastic process that presents the value of the backoff counter for a given station at time slot t. We assume that each STA has $m+1$ stages of backoff delay and that $s(t)$ is the stochastic process representing the backoff stage i at time t. The value of the backoff counter is randomly chosen in the range $(0, W_i - 1)$, where $W_i = 2^i W_{\min}$ and depends on the STA's backoff stage i. The state of each STA is depicted by $\{i, k\}$, where i indicates the backoff stage and takes the values $(0, 1, \ldots\ldots m)$, and k indicates the backoff time slot and takes the values $(0, 1, \ldots\ \ldots, W_i - 1)$ in slot times; the state transition diagram of the Markov chain model is shown in Fig. 3. The transition probabilities are listed as follows:

1. The backoff counter freezes when the STA senses that the channel has another transmission:

$$P\{i,k|i,k\} = p, 0 \le k \le W_i{-}1,\ 0 \le i \le m. \tag{1}$$

2. The backoff counter decrements when the STA senses the channel does not have any transmission:

$$P\{i,k|i,k+1\} = 1{-}p, 0 \le k \le W_i{-}2, 0 \le i \le m. \tag{2}$$

3. The STA enters the $\{-1,0\}$ state if its frame is a successful transmission:

$$P\{-1,0|i,0\} = (1{-}p), 0 \le i \le m. \tag{3}$$

4. The STA transmits its frame without entering the backoff process if it detects that its previously transmitted frame was successfully received and the channel is idle:

$$P\{-1,0|-1,0\} = (1{-}p), 0 \le i \le m. \tag{4}$$

5. If the STA finds that a collision has occurred, the STA defers the transmission to a new frame and enters stage 0 of the backoff process:

$$P\{0,k|-1,0\} = \frac{p}{W_0}, 0 \le k \le W_0{-}1. \tag{5}$$

6. The STA chooses a backoff delay of the next stage i after an unsuccessful transmission at stage $i-1$:

$$P\{i,k|i{-}1,0\} = \frac{p}{W_i}, 1 \le i \le m,\ 0 \le k \le W_i{-}1. \tag{6}$$

7. The STA has reached the last stage of the backoff process and remains at that state after an unsuccessful transmission:

$$P\{m,k|m,0\} \frac{p}{W_m}, 0 \le k \le W_m{-}1. \tag{7}$$

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