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A Performance Study of the IEEE 802.11g PHY and MAC Layers over Heterogeneous and Homogeneous WLANs

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Resumen

Las redes locales inalámbricas (WLANs) basadas en el estándar 802.11 se han extendido con mucho éxito dentro de una gran variedad de ambientes, incluyendo el hogar, las oficinas y las corporaciones. Iniciando con la introducción del estándar 802.11, a la fecha se han propuesto y aprobado diversas extensiones por la IEEE, éstas incluyen los estándares 802.11a, 802.11b y 802.11g. En este trabajo se presenta el análisis de desempeño de las capas físicas (PHY) y de control de acceso al medio (MAC) del estándar IEEE 802.11g. El estándar 802.11g opera en la banda de frecuencia de los 2.4 GHz y es compatible con el estándar 802.11b. Por lo tanto, resulta de gran interés presentar un estudio relacionado con el desempeño de las capas PHY y MAC que se utilizan en 802.11g, incluyendo el desempeño de los modos de operación de la capa física que fueron diseñados para preservar la compatibilidad con 802.11b (i.e. WLANs heterogéneas).

Descriptores: 802.11g, Protocolo MAC, análisis de desempeño, mecanismo de protección, RTS/CTS, WLAN.

Abstract

Wireless local area networks (WLANs) based on the 802.11 standard are being deployed with great success in a great variety of home, office and corporate environments. Since the introduction of the 802.11 standard, multiple extensions have been proposed and approved by the IEEE, namely the 802.11a, 802.11b and 802.11g standards. This work is related to the study and performance analysis of the IEEE 802.11g physical (PHY) and MAC layers. The 802.11g is defined to operate in the 2.4 GHz band and it was designed to preserve backward compatibility with the 802.11b standard. Hence it is important to present a study related to the performance of the MAC and the PHY operational modes in 802.11g, including the performance issues related to the PHY operational modes which are designed to be compatible with 802.11b (i.e. Heterogeneous WLANs).

Keywords: *802.11g, MAC Protocol, Performance Analysis, Protection Mechanism, RTS/CTS, WLAN.*

Introduction

Recent advances on wireless local area networks (WLAN) technologies are making possible the deployment of a large number of WLANs in a great variety of home, office and corporate environments. In particular, the success of the 802.11 standard has made it possible for a great number of products to be readily available at a large number of electronic retail stores. Since the initial introduction of the IEEE 802.11 standard, defined in (IEEE Std.

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802.11-1999), several extensions have been approved by the IEEE. These extensions include the 802.11a (IEEE Std. 802.11a, 1999), 802.11b (IEEE Std. 802.11b, 1999) and 802.11g (IEEE Std. 802.11g, 2003) versions.

The 802.11g standard defines the extensions to the medium access control (*MAC*) mechanism, as well as, the physical layer (*PHY*). One of the main characteristics of the 802.11g standard is that it defines a *PHY* layer operating in the 2.4 GHz band, thus allowing backward compatibility with legacy 802.11b equipment (Vassis *et al*., 2005). As a result, the 802.11g standard defines several *PHY* operational modes to support the compatibility with 802.11b (Choi *et al*, 2003). In addition, a protection mechanism is proposed in the 802.11g standard to avoid interoperability issues within a heterogeneous *WLAN* environment composed of 802.11b and 802.11g devices. Hence it is important to present a study on the performance of the 802.11g standard to have a clear understanding of the operational issues related to the multiple *PHY* operational modes, as well as, the implications or the impact introduced by the protection mechanism proposed in section 9.10 of (IEEE Std. 802.11g, 2003). There are a couple of articles in the literature that present some aspects of the performance of the 802.11g standard. Some related work includes the work by (Wang, S.-C. *et al*., 2005) which presents a mathematical model to evaluate the network throughput of 802.11g wireless networks; however they do not include a complete analysis of the multiple operational *PHY* modes defined in the 802.11g standard. (Wijesinha *et al*., 2005) present throughput performance of UDP traffic in a 802.11g wireless network, while (Medepalli *et al*., 2004) presents the call carrying capacity of 802.11 wireless networks including 802.11g; however they too fail to include a comprehensive performance evaluation of all the mandatory 802.11g extended data rates. (Boulmalf *et al*., 2005) presents the throughput and SNR measurements of an 802.11g wireless network for an indoor environment which includes the coexistence with 802.11b devices; however their work does not provide a detailed analysis of 802.11g by accounting for all the PHY and MAC layers functionalities implemented to support the coexistence with 802.11b and 802.11g devices. (Rao *et al*., 2005) investigates the performance of 802.11g through computer simulations using a realistic channel model for various modulation schemes, like BPSK, QPSK, 16-QAM and 64-QAM; however they only present Bit Error Rate (BER) results as a function of the channel SNR for the different supported modulation schemes. (Wang *et al*., 2005) present empirical network performance results for 802.11g networks and in their work they present packet delay, data loss and throughput measurement results as a function of the channel SNR; however they only consider an homogeneous 802.11g network environment and do not provide performance results for the backward compatibility operational modes of 802.11g. In an earlier work, (Doufexi *et al*., 2003) presents a performance comparison between 802.11a and 802.11g wireless networks and they describe some performance issues related to the interoperability of 802.11b and 802.11g devices; however they only provide performance analysis results as a function of the packet error rate *PER*. The main contribution of this work is to include a comprehensive performance study of all the mandatory operational modes of the 802.11g *PHY* layer, including the performance issues in heterogeneous 802.11b and 802.11g wireless networks.

This work is divided in five sections. The next section presents a description of the new features introduced in the *IEEE* 802.11g standard. Following we present a performance study and analysis of the 802.11g *MAC* protocol. Later, the numerical results are presented followed by the conclusions.

The 802.11g Standard

The *IEEE* 802.11g standard was approved on June 2003. This standard builds on the *MAC* protocol specifications defined for legacy 802.11 networks, as defined in (IEEE Std. 802.11-1999),

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(IEEE Std. 802.11a, 1999) and (IEEE Std. 802.11b, 1999). In addition, it also defines multiple operational modes for the *PHY* layer. This section presents a basic description of some of the *MAC* functionalities, as well as, the operational modes defined for the 802.11g *PHY* layer.

The 802.11 MAC Protocol

The 802.11 *MAC* defines two basic methods to access the medium, the *Distributed Coordination Function* (*DCF*) and the *Point Coordination Function* (*PCF*), as described in chapter 9 of (IEEE Std. 802.11-1999). The *DCF* defines a randomized access mechanism, which is based on the *Carrier Sense Multiple Access/Collision Avoidance* (*CSMA/CA*) scheme, where each mobile node has a fair chance to access the wireless medium. On the other hand, the *PCF* defines a centrally controlled access mechanism for the wireless medium. It should be noted that the 802.11 standard defines the *PCF* as an optional access method. The study and analysis presented in this work is based on the *DCF* access mechanism.

As part of the coordination procedure to gain access to the transmission medium, the 802.11 standard uses four different inter-frame spacing, section 9.2.3 of (IEEE Std. 802.11-1999). Figure 1 shows a diagram of the different *Inter-Frame Spacing* (*IFS*) used in 802.11. The Short Inter-Frame Space (*SIFS*) is used for the transmission of high priority 802.11 frames, such as, the *Request-To-Send* (*RTS*), *Clear-To-Send* (*CTS*) and *Acknowledgement* (*ACK*) frames.

The *PCF Inter-Frame Space* (*PIFS*) is used during *PCF* contention-free operation. The *DCF Inter-Frame Space* (*DIFS*) is used during *DCF* contention-based operation. An *Extended Inter-Frame Space* (*EIFS*), not shown, is also defined in the 802.11 standard and it is used when there is an error during a frame transmission. The *Contention Window* (*CW*) size is defined as a multiple of a time slot, and it plays a major role during the *Backoff* procedure that each mobile node must execute before transmission.

The use of the *IFS* and *CW* is important in the coordination of the access to the wireless medium, as described by (Gast, 2002). Table 1, shows the different inter-frame space values defined in the 802.11g standard which are defined in (IEEE Std. 802.11g, 2003). It should be noted that an optional time slot of 9 µs has been defined for those cases in which the wireless network is composed of only 802.11g complying devices, as indicated in section 19.4.4 of (IEEE Std. 802.11g, 2003).

Table 1. MAC Parameter values in µs

	Time slot = 20	*Time slot* = 9
SIFS	10	10
PIFS	30	19
DIFS	50	28

The minimum size of the *CW*, as defined in the 802.11g standard, is dependant on the requestor's characteristic rate. If the *WLAN* supports only rates in the set 1, 2, 5.5 and 11 Mbps, then the minimum size of the *CW*, denoted by CW_{min}, is equal to the length of 31 time slots, as defined in section 18.3.4 of (IEEE Std. 802.11b, 1999); otherwise, CW_{min} is set to be equal to the length of 15 time slots, as defined in section 19.8.4 of (IEEE Std. 802.11g, 2003).

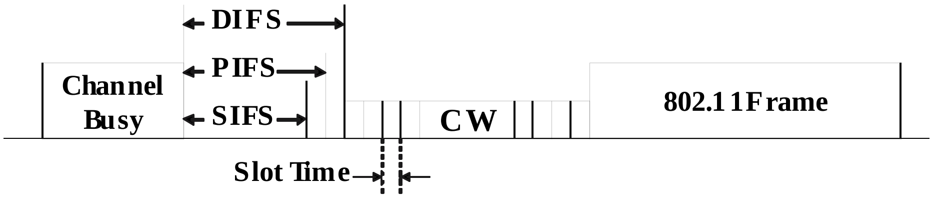

Figure 1. Illustration of the inter-frame spacing in 802.11

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The 802.11g PHY Layer

The 802.11g standard defines several rate extensions, as part of the *Extended Rate PHY* (*ERP*) specification, to the *PHY* for the *Direct Sequence Spread Spectrum* (*DSSS*) implementation. The 802.11g *PHY* specification includes four sets of modulation schemes *ERP-DSSS/CCK* (Mandatory), *ERP-OFDM* (Mandatory), *ERP-PBCC* (Optional) and *DSSS-OFDM* (Optional) (Vassis *et al.* 2005). Figure 2 shows the *PHY* layer *PLCP-PDU* (*PPDU*) packet format of the 802.11g *ERP-DSSS/CCK PHY*, from section 19.3.2.3 of (IEEE Std. 802.11g, 2003). The initial 802.11 standard (IEEE Std. 802.11-1999) defines a long preamble PLCP framing and later in standard (IEEE Std. 802.11b, 1999) a short (optional) preamble for the *PPDU* was defined; however in the 802.11g standard the short preamble *PPDU* capability has been defined as mandatory.

Figure 3 shows the *ERP-OFDM PHY* layer *PPDU* packet format, which is the same as in 802.11a and it is illustrated in section 17.3.2 of (IEEE Std. 802.11a, 1999). An important observation should be made at this point; as part of the operational description of the *ERP-OFDM* modulation scheme, the 802.11g standard specifies that an *ERP* packet is going to be followed by a period of no transmission with a length of 6 µs. This period is called the *signal extension*. The logic behind this is that in the 802.11a standard the *SIFS* length is defined to be 16 µs, this is to

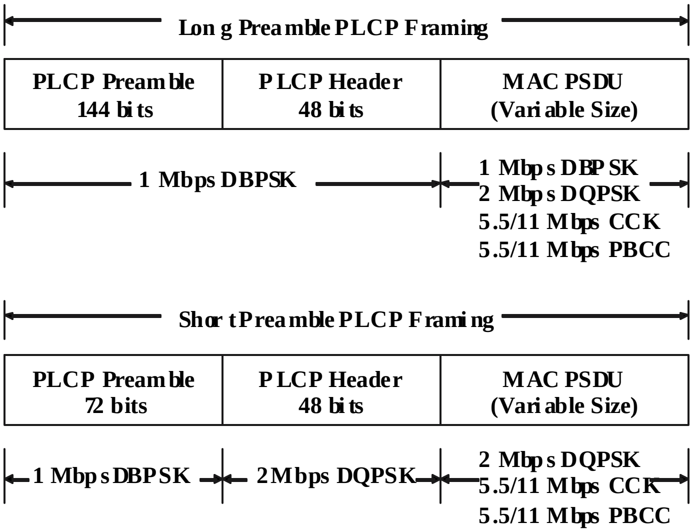

Figure 2. ERP-DSSS/CCK PHY layer PPDU framing

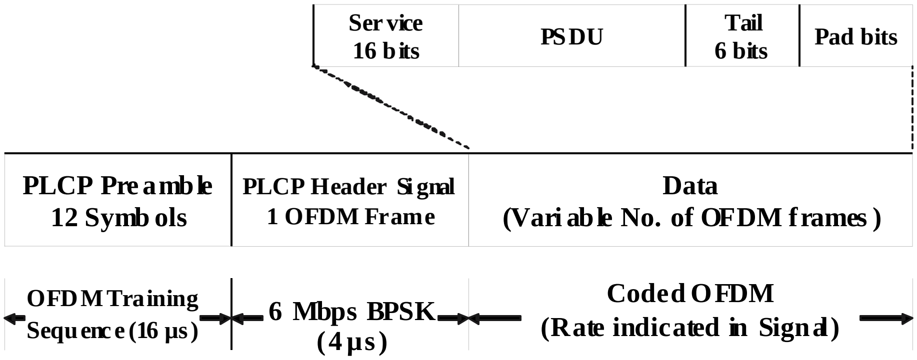

Figure 3. ERP-OFDM PHY layer PPDU framing

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allow for the convolutional decode process to finish, as it is described in section 19.3.2.3 of (IEEE Std. 802.11g, 2003). This assumption also applies to the *ERP-OFDM* in 802.11g, however in the 802.11g standard the *SIFS* length is defined to be 10 μs, presumably to preserve backward compatibility with 802.11b. Nonetheless, in 802.11g, the *ERP-OFDM* modulation scheme still requires 16 μs to ensure the convolutional decoding process to be finished on time. Therefore a signal extension of 6 μs is included so that the transmitting station can compute the *Duration* field in the *MAC* header. This will ensure that the *NAV* value of 802.11b stations is set correctly, as described in section 19.3.2.3 of (IEEE Std. 802.11g, 2003). The performance study presented in this work is based on the two mandatory *ERP PHY* specifications, namely the *ERP-DSSS/CCK* and the *ERP-OFDM* modulation scheme.

Protection Mechanism

The *MAC* sublayer functional description, presented in section 9 of (IEEE Std. 802.11g, 2003), includes a proposal to allow for the interoperability of 802.11b and 802.11g devices. The protection mechanism is introduced to ensure that 802.11g stations, using one of the *ERP* modulation schemes, do not transmit unless they have updated the *Network Allocation Vector* (*NAV*) of the receiving non-*ERP* stations, as described in section 9.10 of (IEEE Std. 802.11g, 2003). The protection mechanism proposes that *ERP* complying stations should transmit *RTS/CTS* or *CTS*-to-self frames before transmitting an *ERP-OFDM* packet. Figure 4, illustrates a time diagram to describe the *RTS/CTS* protection mechanism proposed in the 802.11g standard.

As indicated in section 9.2 of (IEEE Std. 802.11-1999), to support the proper operation of the *RTS/CTS* and the virtual carrier sense mechanisms, all the mobile stations in the *WLAN* shall be able to detect the *RTS* and *CTS* frames. As a result the *RTS* and the *CTS* frames shall be transmitted using one of the rates in the *BSSBasicRateSet* parameter. In addition, the 802.11g standard defines that if the protection mechanism is enabled and if the frame is a protection frame (i.e., *RTS/CTS*) then there are special rules for the transmission rate of these frames. In this case, if any of the rates in the *BSSBasicRateSet* parameter corresponds to an 802.11 or 802.11b rate, then the protection frames should be sent at one of the 802.11 or 802.11b basic rates, as described in section 9.10 of (IEEE Std. 802.11g, 2003). It should be noted that the protection mechanism is not required for the optional *ERP-PBCC* or *DSSS-OFDM* modulation schemes, as these frames start with a *DSSS* header which can be detected and processed by non-*ERP* (e.g. 802.11b) complying devices.

Performance Analysis

This section presents the methodology used in the performance study of the 802.11g standard. The analysis takes into account a variety of issues of the mandatory *PHY* operational modes defined in the 802.11g standard.

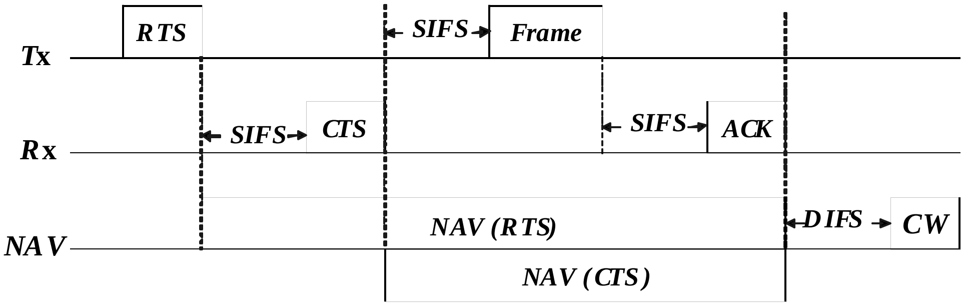

Figure 4. RTS/CTS protection mechanism

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The performance study is divided in two scenarios:

1. The *WLAN* is composed by 802.11b and 802.11g devices (i.e., a heterogenenous *WLAN*).

2. The *WLAN* is composed of only 802.11g devices (i.e., a homogeneous *WLAN*).

The analysis presented in this section is focused on the upper bound performance that can be achieved at the *MAC* layer as a result of the framing structure and the overhead introduced at the *MAC* and *PHY* layers. In this work we are not concerned with the performance degradation due to network load and we only consider a scenario where a single station is transmitting data to another station, thus it is assumed that the station makes a successful transmission immediately after the *CW* period.

WLAN with 802.11b and 802.11g devices

In this scenario the *WLAN* is composed by 802.11b and 802.11g devices. Thus an 802.11g complying device can operate in any of the *ERP-DSSS/CCK*, *ERP-OFDM* mandatory modulation schemes. Recall that the 802.11b stations can detect *ERP-DSSS/CCK PPDU* packets. However, this is not the case when *ERP-OFDM PPDU* packets are transmitted by the 802.11g stations. In this case, the 802.11g devices must introduce the protection mechanism, described in (IEEE Std. 802.11g, 2003), or an alternative one as described by (Choi, 2003); this will ensure that the 802.11b devices will not transmit while the channel is busy.

The *MAC* throughput, $MAC_{th\text{-}DSSS}$, for the *ERP-DSSS/CCK* modulation scheme is defined in equation 1, while the *MAC* throughput, $MAC_{th\text{-}OFDM}$, for the *ERP-OFDM* scheme with protection mechanism (e.g., in a heterogeneous *WLAN*) is defined in equation 2,

$$MAC_{th\text{-}DSSS} = \frac{MAC\_PSDU\_Size}{DIFS + CW_t + SIFS + F_t + ACK_t} \ , \tag{1}$$

$$MAC_{th\text{-}OFDM} = \frac{MAC\_PSDU\_Size}{DIFS + CW_t + (3^2 SIFS) + F_t + RTS_t + CTS_t + ACK_t} \tag{2}$$

where, *DIFS* represents the *DCF* inter-frame spacing time, CW_t is the average time length of the contention window, *SIFS* is the short inter-frame spacing time, F_t represents the time it takes to transmit the *PPDU* frame, RTS_t, CTS_t and ACK_t represents the time it takes to transmit an *RTS*, *CTS* and *ACK* frame respectively. It should be noted that expressions (1) and (2) do not account for those cases where the *MAC PSDU* must be fragmented at the *PLCP* sublayer, in which case, each *PPDU* frame fragment is fallowed by a *SIFS* plus an *ACK* frame.

WLAN with only 802.11g devices

In this scenario the *WLAN* is entirely composed by 802.11g complying devices. In this case there is no requirement to use the *RTS/CTS* protection mechanism, other than to guarantee reservation of the wireless medium and to avoid the hidden node problem.

Figure 5, shows a time diagram of the transmission of an *ERP-OFDM PPDU*. In this case the *MAC* throughput is evaluated as indicated in expression (1).

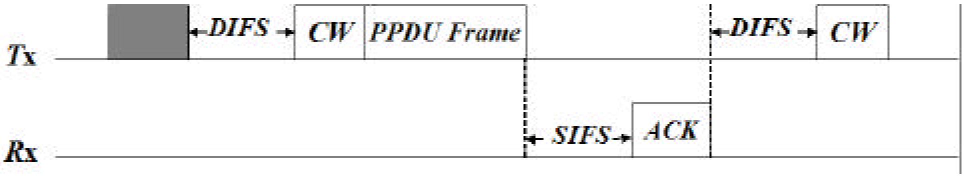

Figure 5. PPDU transmission time diagram

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Numerical Results

This section presents the numerical results of the *MAC* throughput for a heterogeneous and a homogeneous 802.11g wireless network. This section is divided in two subsections. The first subsection deals with a heterogeneous 802.11b and 802.11g wireless network scenario. The second subsection deals with a homogeneous 802.11g wireless network scenario.

Heterogeneous 802.11b and 802.11g WLAN

This section presents the performance analysis results of the *MAC* throughput for the two mandatory modulation schemes defined in the 802.11g standard, namely the *ERP-DSSS/CCK* and the *ERP-OFDM* modulation schemes.

ERP-DSSS/CCK Results

In this scenario the 802.11g complying devices transmit using the *ERP-DSSS/CCK* modulation scheme. As the non-802.11g complying devices can detect the *ERP-DSSS/CCK* messages, there is no need to introduce the *RTS/CTS* protection mechanism. Table 2 shows the *MAC* parameter values used for calculations in this section. The numerical results are presented for the case of short and long preambles.

Table 2. ERP-DSSS/CCK parameter values in µs

	Short *PLCP*	Long *PLCP*
DIFS	50	50
SIFS	10	10
CWt	150	150
PLCP Preamble	72	144
PLCP Header	24	48

The average length of the contention window, CW_t, is calculated as the expected value of a uniform random variable in the range [0, CW_{min}]. The value of CW_{min} increases with the number of retransmissions. It should be noted that the 802.11g standard defines an initial CW_{min} value of 15 time slots, while the maximum value of the contention window is limited by the physical layer. For the case of a direct sequence (*DS*) *PHY* Layer the maximum length of the contention windows is 1,023. For the purpose of the analysis presented in this section, the value of CW_{min} is 15 time slots and the time slot duration is equal to 20 µs.

The value of F_t, which represents the time it takes to transmit the *PPDU* frame, is defined as,

$$F_t = PLCP_P + PLCP_H + \frac{MAC\_PSDU\_Size}{PHY_{rate}}$$

(3)

where, $PLCP_P$ and $PLCP_H$ represent the length of time required to transmit the *PLCP* preamble and the *PLCP* header, respectively. The *MAC_PSDU_Size* can have a maximum size of 2,346 bytes, which includes a variable size *Frame Body* of 0 – 2 312 bytes and several control fields with a total length of 34 bytes (Heiskala *et al*., 2002). The set of *PHY* layer data rates, PHY_{rate}, considered for this scenario include 1, 2, 5.5 and 11 Mbps.

Figure 6 shows the MAC performance results of the *ERP-DSSS/CCK* modulation scheme using the Long Preamble *PLCP* Framing format. The numerical results are presented for different lengths of the *MPDU* and at the four *ERP-DSSS/CCK* date rates: 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps. Figure 7, shows the *MAC* performance results assuming the Short Preamble *PLCP* framing format. The numerical results are presented for different lengths of the *MPDU* and at date rates of 2, 5.5 and 11 Mbps, which are supported with the short preamble framing format, as described in section 18.2.2.2 of (IEEE Std. 802.11b, 1999).

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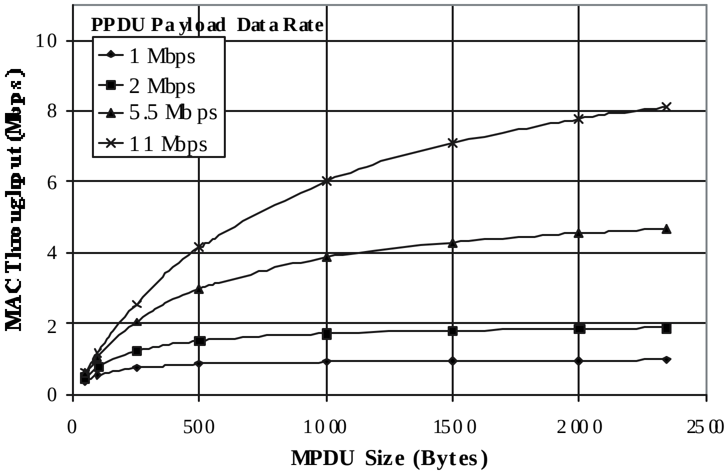

Figure 6. ERP-DSSS/CCK MAC Throughput (Long Preamble)

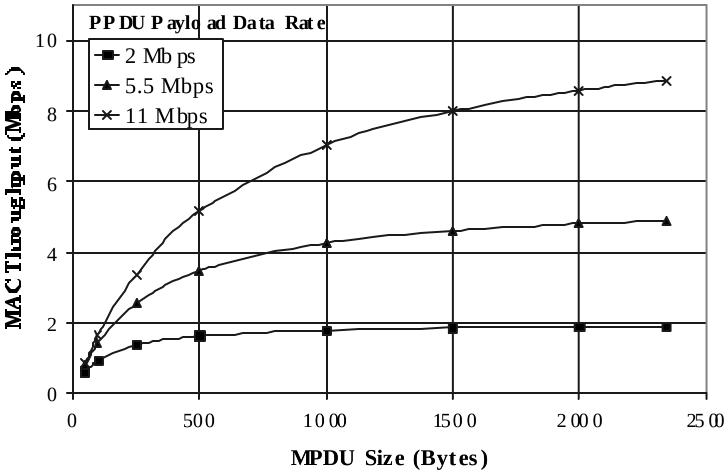

Figure 7. ERP-DSSS/CCK MAC Throughput (Short Preamble)

ERP-OFDM Results

In this scenario the 802.11g complying devices transmit using the *ERP-OFDM* modulation scheme. As the non-802.11g complying devices cannot detect the *ERP-OFDM* messages, there is a need to introduce the *RTS/CTS* protection mechanism. It should be noted that the *RTS* and *CTS* frames are transmitted at one of the basic rates defined in 802.11b. For the purpose of this work only the 2 Mbps and 11 Mbps basic rates of 802.11b are considered. In addition, the numerical results include the two possible cases in which the *RTS/CTS* frames are transmitted with a short or a long *PLCP* framing. Table 3 shows the *MAC* parameter values of the *ERP-OFDM* modulation scheme used for calculations in this section. The numerical results are presented assuming a time slot length of 20 µs.

Table 3. ERP-OFDM parameter values in µs

	Time slot =20 µs

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DIFS	50
SIFS	10
CW_t	150

The average length of the contention window, CW_t, is calculated as the expected value of a uniform random variable in the range [0, CW_{min}]. For the purpose of the analysis presented in this section, the value of CW_{min} is 15 time slots. It should be noted that the numerical results account for the extended service period of 6 μs after each *ERP-OFDM PPDU* frame transmission.

From the results presented in figure 8 to figure 11, it is clear that the *MAC* Throughput is not significantly affected by transmitting the *RTS/CTS* frames at 2 or 11 Mbps. This is explained by the fact that only the *RTS/CTS* frame body is transmitted at 2 or 11 Mbps and the *RTS/CTS* payload field is small. On the other hand, the use of a short or a long preamble has a greater impact on the *MAC*

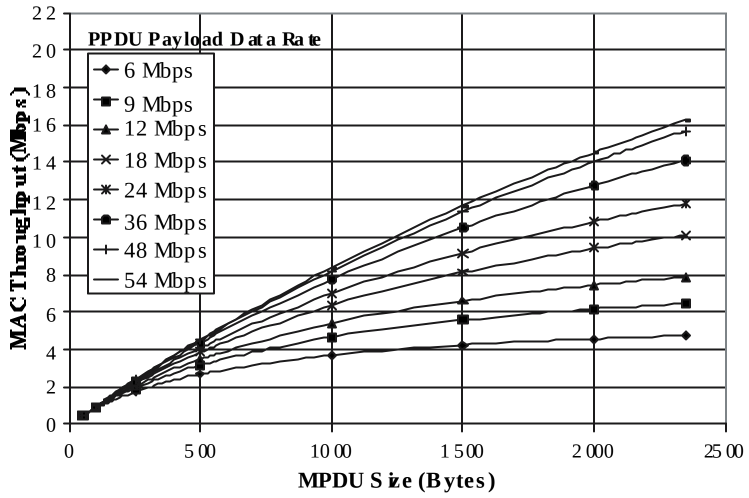

Figure 8. ERP-OFDM MAC Throughput (RTS/CTS at 2 Mbps with Long Preamble)

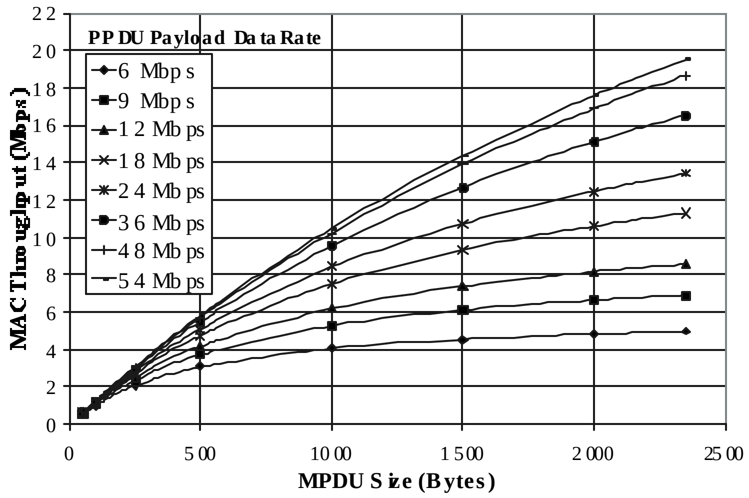

Figure 9. ERP-OFDM MAC Throughput (RTS/CTS at 2 Mbps with Short Preamble)

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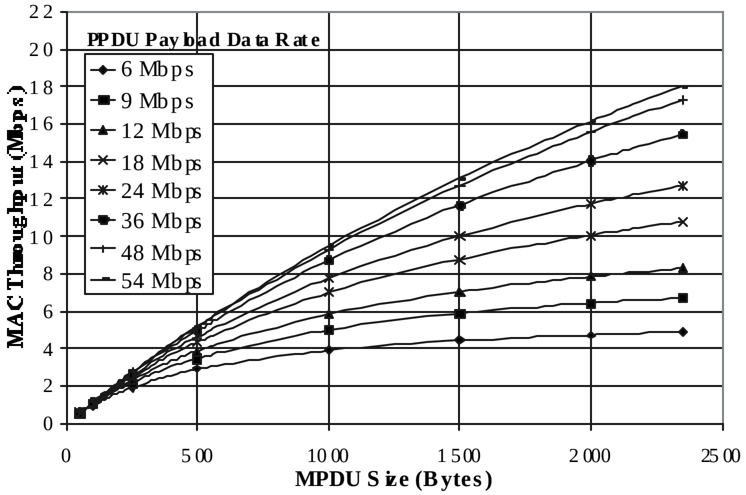

Figure 10.ERP-OFDM MAC Throughput (RTS/CTS at 11 Mbps with Long Preamble)

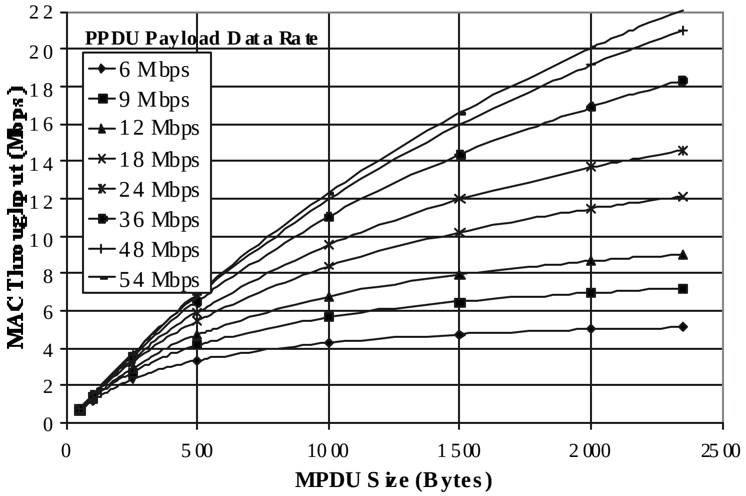

Figure 11. ERP-OFDM MAC Throughput (RTS/CTS at 11 Mbps with Short Preamble)

Throughput; this is especially true for high *PPDU* payload data rates.

Homogeneous 802.11g WLAN

In this scenario the 802.11g complying devices transmit using the *ERP-OFDM* modulation scheme in an 802.11g homogeneous environment (i.e., the *WLAN* is composed only by 802.11g complying devices).

Then the 802.11g devices can transmit at any of the *ERP-OFDM* data rates without the need of an *RTS/CTS* protection scheme, unless there is a need for the reservation of the channel or to avoid the hidden node problem.

ERP-OFDM Results

The *MAC* performance results assume a time slot length of 9 µs, as described in (IEEE Std. 802.11g, 2003). The average length of the con-

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tention window, CW_t, is calculated as the expected value of a uniform random variable in the range [0, CW_{min}]. For the purpose of the analysis presented in this section, the value of CW_{min} is 15 time slots. In addition, the *MAC* performance results account for the extended service period of 6 µs after each *PPDU* frame transmission.

Table 4 shows the *MAC* parameter values used for calculations in this section. The numerical results are presented assuming a time slot length of 9 µs.

Table 4. ERP-OFDM parameter values in µs

	Time slot (9 µs)
DIFS	28
SIFS	10
CW_t	67.5

The results presented in figure 12 show an increased *MAC* Throughput, compared to the *ERP-OFDM* scheme in a heterogeneous *WLAN*. The *MAC* Throughput is almost twice in the *ERP-OFDM* in a homogeneous *WLAN* than that in a heterogeneous *WLAN* for a *MPDU* size of 2,346 and payload data rate of 54 Mbps. This result clearly indicates that the introduction of the *RTS/CTS* protection mechanism has a major impact on the performance of the *ERP-OFDM* modulation scheme, especially for high payload data rates.

Conclusions and Future Work

A performance study and analysis of the 802.11g *MAC* protocol is presented in this article. The most recent extension to the 802.11 standard, namely the 802.11g, defines multiple *PHY* operational modes. Some of these *PHY* operational modes are backward compatible with the 802.11b standard, while other *PHY* operational modes will require some sort of protection mechanism to allow for the interoperability of 802.11b and 802.11g devices within a heterogeneous *WLAN*, as described in (IEEE Std. 802.11g, 2003). In a heterogeneous *WLAN* an 802.11g complying device can operate using the *ERP-DSSS/CCK* or the *ERP-OFDM* modulation schemes. In general, a higher *MAC* efficiency is achieved under the *ERP-DSSS/CCK* modulation scheme. This result is explained by the fact that 802.11g complying devices must introduce the *RTS/CTS* protection mechanism when operating under the *ERP-OFDM* modulation scheme. On the other hand, in a homogeneous *WLAN*, the 802.11g devices can operate in the *ERP-OFDM* modulation scheme without the need of introducing the *RTS/CTS* protection mechanism, unless there is

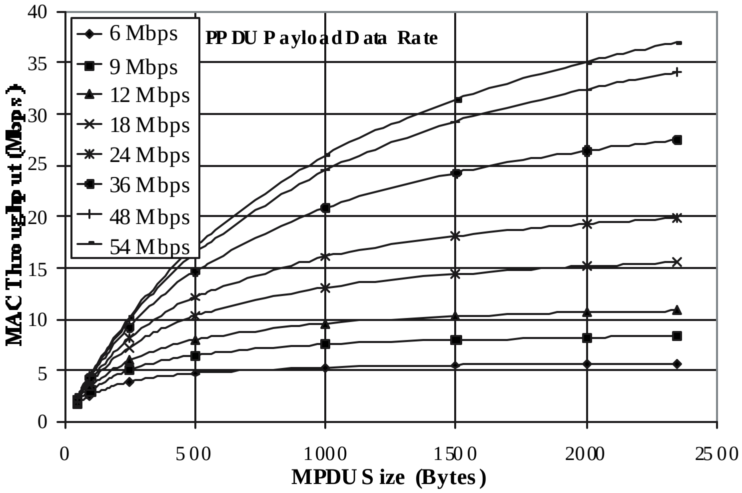

Figure 12. ERP-OFDM MAC Throughput (Time slot = 9 µs)

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a need to guarantee the reservation of the wireless medium or to avoid the hidden node problem. In addition, in the case of a homogeneous *WLAN*, the CW_{min} size and the time slot length can be reduced, to 15 and 9 µs respectively, to allow for an improved *MAC* efficiency. Future work will consider the performance analysis of the 802.11g standard by accounting for the wireless network load and the impact that the wireless fading channel has on the transmission of 802.11g frames.

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