802.11g CP: A Solution for IEEE 802.11g and 802.11b Inter-Working

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Abstract—IEEE 802.11g is an emerging standard for a high data rate physical (PHY) layer supporting up to 54 Mbps at 2.4 GHz for wireless local area networks (WLANs). IEEE 802.11g is defined to be a superset of the 802.11b PHY. It includes the 802.11b modulation schemes and other higher rate modulation schemes, such as the Orthogonal Frequency Division Multiplexing (OFDM) schemes originally defined for 802.11a PHY at 5 GHz. One major problem with the 802.11g is that the OFDM signal is not detected by many legacy 802.11b devices operating at 2.4 GHz, and hence it introduces a severe problem since the 802.11 Medium Access Control (MAC) is based on carrier-sensing. The 802.11g draft specification recommends the exchange of Request-To-Send (RTS)/Clear-To-Send (CTS) frames modulated with an 802.11b scheme before the transmission of the actual OFDM data frame. However, the RTS/CTS exchanges involve a large bandwidth waste. We propose an alternative solution, which improves the system throughput by avoiding the costly RTS/CTS usage. Our proposed solution utilizes the characteristics of the existing MAC with a minimal rule change, which requires virtually no change in the existing MAC implementations.

I. INTRODUCTION

During the past few years, the IEEE 802.11 wireless local area network (WLAN) has emerged as a prevailing broadband indoor wireless networking technology [5][6]. It is being deployed widely across the enterprise, home, and public environments. The IEEE 802.11 specification defines a single medium access control (MAC) along with multiple PHY layers [1][2][3][5]. An IEEE 802.11 device runs the MAC along with at least one PHY. Today, IEEE 802.11b physical (PHY) layer [3], supporting transmission rates ranging from 1 to 11 Mbps via Complementary Code Keying (CCK) and Direct Sequence Spread Spectrum (DSSS) modulation schemes at 2.4 GHz, is the most widely used PHY. A new higher-speed PHY, IEEE 802.11a [2], supporting rates from 6 to 54 Mbps via Orthogonal Frequency Division Multiplexing (OFDM) at 5 GHz, is also emerging in the market. The 802.11a can support faster transmissions than 802.11b, but it does not interoperate with 802.11b since it operates in a different frequency band. Therefore, many have looked for a faster system at 2.4 GHz, which can inter-work with the legacy 802.11b systems.

Accordingly, IEEE 802.11 Working Group started defining a new PHY, called 802.11g, as an extension to the 802.11b to support over 20 Mbps transmission rates at 2.4GHz. Currently, the standardization of the 802.11g is at the final stage. According to the draft specification of the 802.11g [4], the 802.11g is a superset of the 802.11b. It includes the CCK/DSSS modulations, the 802.11a OFDM modulation schemes modified for the 2.4 GHz operation, and two other optional modulation schemes. The OFDM mode is called Extended Rate PHY-Orthogonal Frequency Division Multiplexing (ERP-OFDM).

By nature, the 802.11g stations should co-exist with the 802.11b stations in the same location, the same frequency band, and the same network coordinated by a single access point (AP). We expect to see the networks with both 802.11g and 802.11b devices often in the near future as 802.11b devices are widely deployed and used out there today. However, the 802.11g holds a serious problem when it co-exists with the 802.11b because many legacy 802.11b devices cannot detect the ERP-OFDM signals on the air, and it can result in collisions between frames from 802.11b and 802.11g stations. The draft specification suggests a solution, which is based on the channel reservation for the ERP-OFDM transmissions. NonERP (or equivalently DSSS/CCK-modulated) Request-to-Send (RTS)/Clear-to-Send (CTS) exchange is used to reserve the channel. In this paper, we evaluate the suggested mechanism, and demonstrate that it is a very costly solution. Then, we propose a new solution, called the 802.11g Contention Period (CP), which turns out to achieve a better system performance.

The rest of the paper is organized as follows: Section II overviews the IEEE 802.11g PHY, then Section III identifies the problems with the nonERP RTS/CTS exchange recommended by the draft specification. We propose our solution in Section IV, and compare our solution with the nonERP RTS/CTS solution via the simulations in Section V. Finally, this paper concludes with Section VI.

II. IEEE 802.11G EXTENDED RATE PHY (ERP) [4]

IEEE 802.11g basically includes four different sets of modulation schemes as follows:
- **Mandatory** nonERP, i.e., IEEE 802.11b PHY including DSSS for 1 and 2 Mbps, and CCK for 5.5 and 11 Mbps;
- **Mandatory** ERP-OFDM, which is the 2.4 GHz version of the IEEE 802.11a PHY (defined for 5 GHz), supporting 8 different PHY modes for 6 to 54 Mbps;
- **Optional** Extended Rate Packet Binary Convolutional Code (PBCC), which is an extended version of the optional PBCC mode of IEEE 802.11b, for 22 and 33 Mbps; and
- **Optional** CCK-OFDM, which is a hybrid modulation combining a DSSS preamble and header with an OFDM payload transmission, supporting 8 different PHY modes for 6 to 54 Mbps.

The 2.4 GHz ISM band is a shared media and co-existence with other devices such as IEEE 802.11b is an important issue for maintaining high performance in 802.11g devices. One major problem is that many legacy 802.11b devices cannot detect the ERP-OFDM signals on the air. This is because only one of the three clear channel assessment (CCA) modes specified in the IEEE 802.11b standard needs to be implemented [3], and the most common implementation does not indicate a busy channel unless DSSS/CCK signals are detected. That is, these 802.11b devices will assume that the channel is idle even if there is an 802.11g ERP-OFDM signal on air. Note that this kind of co-existence problem does not exist with the optional Extended Rate PBCC and CCK-OFDM since they use the DSSS preamble and header.

The mandatory mode of the 802.11 Medium Access Control (MAC) protocol called the distributed coordination function (DCF) is based on Carrier Sensing Multiple Access (CSMA), which basically attempts to transmit a pending frame only when the transmitting station knows that there is no other signal on air, i.e., the channel is idle. Therefore, the fact that the 802.11b stations cannot see the ERP-OFDM signals introduces a serious problem to achieve a proper operation in the 802.11g and 802.11b mixed networks.

The 802.11g specification recommends the exchange of RTS/CTS frames modulated with a DSSS/CCK scheme, called nonERP RTS/CTS, before the transmission of the actual data frame [4]. The RTS/CTS makes the channel virtually busy during the transmission of the subsequent data frames by setting the Network Allocation Vector (NAV) counters in all the receiving stations including 802.11b stations. This prohibits the 802.11b stations from contending for the channel during the time specified in the RTS/CTS exchange, even if they sense the medium idle, allowing the 802.11g to use faster ERP-OFDM modulation schemes for the data transmissions. This recommended solution should work thanks to the nature of the RTS/CTS exchange and NAV protection. However, as explained below, it has some inherent problem, and introduces an unnecessarily high overhead.

### III. Problem Statement

The proposed nonERP RTS/CTS may not work in certain environments due to the NAV reset rule defined in subclause 9.2.5.4 of [1]. That is, after receiving an RTS frame, if the station does not receive any frame within a certain amount of time, which is roughly the sum of the subsequent CTS and some extra time, the station can reset the NAV. For this kind of devices, the proposed nonERP RTS/CTS may not work in some cases since these devices may reset the NAV when there is an ERP-OFDM data frame transmission after the nonERP RTS/CTS exchange. Fortunately, this NAV reset rule is optionally defined, and there are not that many devices in the market that follow this rule.

Practically, the problem with the nonERP RTS/CTS exchange is the incurring big overhead. Fig. 1 shows the transaction times of a 1500-octet long frame for different PHY options. A frame transaction time under the DCF includes (1) the average medium access time including the DCF Interframe Space (DIFS) and backoff times; (2) RTS transmission time; (3) CTS transmission time; (4) data frame transmission time; and (5) ACK frame transmission time. The Short Interframe Space (SIFS) used between two consecutive frames is also considered. The RTS/CTS exchange time is drawn only if the exchange is assumed. Six different cases are considered as follows:

- 802.11g 54 Mbps with short-preamble RTS/CTS
- 802.11g 54 Mbps with long-preamble RTS/CTS
- 802.11g 54 Mbps without RTS/CTS
- 802.11b 11 Mbps with short-preamble frames
- 802.11b 11 Mbps with long-preamble frames
- 802.11a 54 Mbps without RTS/CTS

All the relevant MAC parameter values are found in Table I.

![Fig. 1. Frame transaction times for different PHY options.](chart.png)

<table>
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<tr>
<th>MAC PARAMETER VALUES (IN µsec) FOR DIFFERENT PHYS</th>
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For 54 Mbps data transmissions, the RTS/CTS and ACK frames are transmitted at 2 (i.e., nonERP) and 24 Mbps, respectively, while the RTS/CTS and ACK frames are both transmitted at 2 Mbps for 11 Mbps data transmissions. Note that the IEEE 802.11b defines two different PHY preamble schemes: the mandatory long preamble and the optional short preamble. As listed above, for the 802.11b, we consider both preamble options, where both the data and ACK frames use either option, respectively. The long preamble apparently introduces a larger overhead. While many 802.11b devices in the field implement both long and short-preamble options, there are still quite many devices, which do not understand the short-preamble option. Therefore, we believe that the 802.11g devices need to transmit nonERP RTS/CTS frames using the long-preamble option.

Unfortunately, we observe from Fig. 1 that the frame transaction time of 802.11g with long-preamble nonERP RTS/CTS is about a double of that of 802.11g without RTS/CTS exchange. It should be also noted that the transaction time for the 802.11g without RTS/CTS exchange is longer than that of the 802.11a. This is due to the longer SIFS and backoff delay as can be determined from TABLE I.

IV. 802.11G CP: OUR SOLUTION FOR INTER-WORKING

We propose an alternative solution that can avoid the nonERP RTS/CTS usage, which, as we have demonstrated, wastes considerable amount of bandwidth unnecessarily. We utilize the characteristics of the existing MAC with a minimal rule change as follows.

The 802.11 MAC defines two different coordination functions: the mandatory DCF and the optional point coordination function (PCF). The PCF is based on a poll-and-response scheme. In order to use the PCF, the time axis is repetitively divided into superframes. A superframe is composed of a contention-free period (CFP) and a contention period (CP), during which PCF and DCF are used, respectively. Basically, during a CFP, the stations do not contend for the channel as their NAV is set to a pre-defined value, CF_Max_Duration, at the beginning of each CFP. Instead, a station transmits a frame upon receiving a polling frame from the access point (AP). A CFP ends when the AP transmits a CF-End frame, which resets the NAV value in each station upon reception. Then, a CP starts, and all the stations start contending for the channel using the DCF. For this purpose, the CF-End frame is transmitted at one of the transmission rates, which can be understood by all the stations in the network. A timing diagram of the PCF operation during a CFP is shown in Fig. 4.

As noted above, the PCF operation is optional, that is, not every 802.11 station will be able to respond with a data frame in a SIFS interval after receiving a polling frame from the AP. This capability is called “CF-pollable.” However,
every 802.11-compliant station must be “CF-aware,” which means that a station understands the existence of the CFP and CP, and sets a NAV value to the CF_Max_Duration at the target beacon transmission time (TBTT), at which a CFP is supposed to start. Basically, the CF-awareness implies that a station does not contend for the channel during the CFP, and resumes the contention per the expiration of the NAV counter or the reset of the NAV by receiving a CF-End frame.

...equivalently, when the original NAV that was set according to the CF_Max_Duration expires. This is shown in Fig. 7. There are two possible ways to determine the T_extra as follows: (1) option I – an 802.11g station starts using nonERP RTS/CTS beginning a large fixed time (determined by the maximum frame transmission time) before the end of the 802.11g CP; and (2) option II – a 802.11g station uses RTS/CTS only if its pending frame transmission transaction cannot be finished before the end of the 802.11g CP. The fixed T_extra based on option I is determined to be 4.8 msec, which corresponds to the frame transmission time needed to transmit a 2304-octet MSDU with 11 fragments.2 Option II is more complex, but should increase the performance of the network, since the 802.11g CP usage could be maximized. 

Fig. 6. Illustration of the collision of an ERP frame, which starts being transmitted within the 802.11g CP.

V. SIMULATION RESULTS

In this section, we demonstrate the superiority of the proposed mechanism to the nonERP RTS/CTS exchange. We use the OPNET network simulator for this simulation. The original OPNET model supports the 802.11b PHY, and hence we added the 802.11g ERP-OFDM rates into the existing model. We consider two scenarios for the evaluation.

In the first scenario, there are four 802.11b stations and four 802.11g stations, respectively. All the stations are assumed to have infinite amount of traffic, which will make the network overloaded, and each data frame has a 1500-octet long payload. The 802.11g stations transmit the data and ACK frames at 24 Mbps while transmitting the nonERP RTS/CTS frames at 2 Mbps using the long-preamble option. The 802.11b stations transmit the data and ACK frames at 11 and 2 Mbps using the long-preamble option, respectively. The beacon interval (or superframe size) is 100 msec, and the maximum MSDU size served by the IEEE 802.11 MAC is 2304 octets, and the maximum number of possible fragments from a single MSDU is 11.
CF_Max_Duration is assumed 50 msec. The CF-End frame is transmitted right after a beacon frame at 24 Mbps. Therefore, the 802.11g CP is roughly 50 msec long. Note that virtually there is no CFP, and only the DCF mode is used.

Fig. 8 shows the aggregated system throughput for three different cases: (1) using RTS/CTS always (blue); (2) using 802.11g CP with option I above (red); and (3) using 802.11g CP with option II above (green). The usage of the proposed 802.11g CP clearly achieves higher system throughput while option II achieves a slightly larger throughput. This clearly demonstrates that the proposed scheme enhances the system performance of the 802.11g and 802.11b mixed networks.

In the second scenario, we change the traffic generation so that the 802.11b stations start its generation/transmission beginning at 30 seconds in the simulation time. We assume that the 802.11g stations use the nonERP RTS/CTS even if there is no 802.11b traffic on air. Note that it is not possible for the 802.11g stations to know when an 802.11b station starts transmitting its frames. In Fig. 9, we basically observe the aggregate throughput decreases beginning at 30 sec, but the general trend, i.e., the fact that our schemes achieve the higher system throughput, remains the same.

VI. CONCLUSION

The IEEE 802.11g is the emerging high-speed PHY defined for 2.4 GHz ISM band. Due to the nature of the legacy 802.11b running at the same band, the co-existence between the 802.11g and 802.11b becomes an issue. While the draft specification recommends using the nonERP RTS/CTS exchange in order to protect the ERP-OFDM transmissions, we demonstrate that it is a very costly solution. By including a minimal change in the MAC operation rule, we propose a solution called the 802.11g CP, which turns out to achieve a much better system throughput when the 802.11g and 802.11b stations co-exist in the same network. Moreover, our solution requires virtually no change in the existing MAC implementation.

REFERENCES