Understanding the Features of IEEE 802.11g in High Data Rate Wireless LANs

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ABSTRACT
In a practical application scenario, high data rates are required with increasing demand of wireless LANs. To upgrade the data rate of WLANs, the IEEE presented the IEEE 802.11g standard for providing higher data rates up to 54 Mbps at the 2.4 GHz frequency band. In this paper, performance of IEEE 802.11g standard is described with respect to WLANs. The review study of this paper provides the features of IEEE 802.11g by comparing it with previous IEEE standards to evaluate the efficiency of WLANs.

Keywords
Wireless LANs, IEEE 802.11g

1. INTRODUCTION
For three different physical layers that is direct sequence spread spectrum (DSSS), frequency hopping spread spectrum (FHSS), and infrared (IR) techniques, the IEEE 802.11 standard [1] defines data rates of 1Mbps to 2 Mbps. To provide higher data rates, the DSSS is one of the most widely used technique from those three physical layers. The IEEE 802.11a [2] defines an orthogonal frequency division multiplexing (OFDM) technique for multicarrier transmission to provide data rates from 6 Mbps to 54 Mbps at 5 GHz band. Although IEEE 802.11a standard upgrades the usable data rates from 11 Mbps to 54 Mbps at 5GHz band but it cannot support interoperability with older IEEE 802.11 and IEEE 802.11b devices. The IEEE 802.11g standard [3] combines the features of both standard (IEEE802.11a and IEEE802.11b) to support data rates of up to 54 Mbps at the 2.4 GHz band, hence provide interoperability with IEEE 802.11 and IEEE 802.11b devices. In present wireless networks, to enhance the data rate of wireless connections for various applications, the IEEE 802.11-based wireless local area networks (WLANs) have been widely utilized. On this context, the IEEE published the IEEE 802.11b standard to provide data rates of up to 11 Mbps at the 2.4 GHz band. By employing the most recent modulation techniques, the advanced IEEE 802.11a [4] and IEEE 802.11g [5] standards are utilized, which provide higher wireless bandwidth. This paper provides a detailed description of the features of 802.11g standard and discusses its performance by comparing it to the previous IEEE 802.11 standards. A major advantage of 802.11g standard is enhancing a system that specifies a smooth and incremental upgrade without actuating the old arrangements shortly.

2. IEEE 802.11g WLAN STANDARD
The IEEE 802.11g standard was developed to enhance the data rates faster than 20 Mbps. The 802.11g standard provides backward compatibility with 802.11b devices to protect the investments in present wireless LAN installations. Here, some new features defined by the IEEE 802.11g standards for enhancing the data rate of WLANs.

2.1 Providing Four Different Physical Layers
Although IEEE 802.11b standard operates at 2.4 GHz frequency band by using DSSS technology with either the packet binary convolution coding (PBCC) algorithm or complementary code keying (CCK) modulation. IEEE 802.11a standard uses an orthogonal frequency division multiplexing (OFDM) physical layer to provide data rates up to 54 Mbps at the 5 GHz unlicensed national information infrastructure (U-NII) band. IEEE 802.11g uses DSSS, OFDM or both to provide transmission of data rates up to 54 Mbps at the 2.4 GHz ISM band. IEEE 802.11g combines the features of IEEE 802.11 [6], IEEE 802.11a [7] and IEEE 802.11b [8]. As a result, combine application of both DSSS and OFDM is obtained by the provision of four different physical layers. The sender and receiver can choose and usage one of the four layers during a frame exchange since they both support it. Extended rate physicals (ERPs) standard defines these layers. The four different layers defined by the IEEE 802.11g standard are:

ERP-DSSS/CCK— This old physical layer was introduced by IEEE 802.11b. The 802.11b specifications enhanced the data rate and maintained compatibility with the original 802.11 DSSS standard. It uses a more efficient coding scheme known as complementary code keying (CCK) to provide a data rate of 11 Mbps.

ERP-OFDM— IEEE 802.11g defined this physical layer. IEEE 802.11a usage a multi-carrier modulation schemes that is orthogonal frequency division multiplexing (OFDM) by utilizing the 2.4 GHz radio spectrum to provide data rates from 6 Mbps to 54 Mbps.

ERP-DSSS/PBCC— This physical layer offers same data rates as the DSSS/CCK physical layer. DSSS/PBCC was introduced by IEEE 802.11b. It is used to provide higher performance in the range at the 5.5 and 11 Mbps rates by using DSSS technology with Packet Binary Convolution code (PBCC) scheme. The IEEE 802.11g standard upgraded the data rates by using those of 22 and 33 Mbps.

DSSS-OFDM— A hybrid combination of DSSS and OFDM is utilized by this new physical layer. The transmission of packet physical header is done by DSSS, whereas the transmission of packet payload is performed by OFDM. This physical layer usage to cover interoperability aspects.

The first two physical layers must be supported by each IEEE 802.11g devices. The last two physical layers are arbitrary from the above four physical layers. The different IEEE 802.11g physical layers parameters [9] are given in table 1.

Table 1. The different IEEE 802.11g physical layers parameters

<table>
<tr><th rowspan="2">Physical layer</th><th rowspan="2">Data rates (Mbps)</th><th colspan="2">PLCP preamble +header delay</th><th colspan="2">PLCP preamble + header length</th></tr>
<tr><th>Short</th><th>Long</th><th>Short</th><th>Long</th></tr>
<tr><td>ERP- DSSS (Essential)</td><td>1 ,2, 5.5,11</td><td>96µs</td><td>192 µs</td><td>120 bits</td><td>192 bits</td></tr>
<tr><td>ERP-OFDM (Essential)</td><td>6, 9,12, 18,24, 36, 48, 54</td><td colspan="2">20µs</td><td colspan="2">40 bits</td></tr>
<tr><td>ERP- PBCC (Arbitrary)</td><td>1,2,5.5, 11, 22, 33</td><td>96µs</td><td>192 µs</td><td>120 bits</td><td>192 bits</td></tr>
<tr><td>DSSS-OFDM (Arbitrary)</td><td>6, 9,12, 18,24, 36, 48, 54</td><td>96µs</td><td>192 µs</td><td>120 bits</td><td>192 bits</td></tr>
</table>

2.2 Extended rate PHY Specification

When 802.11b stations present in the network, then IEEE 802.11g supports 20µs slot time and 31 slots of minimum contention window of 802.11b. These parameters are accommodated to enhance the performance with DSSS modulation. The IEEE 802.11g supports data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps, whereas the 802.11b supported data rates of 1, 2, 5.5 and 11 Mbps [10]. The values of time slot and minimum contention window reduce the performance of network, when a station uses ERP-OFDM data rates (6-54 Mbps).ERP network attributes defines the dynamic adjustment values of the time slot and minimum contention window incorporating with the IEEE 802.11g standard. When all stations related to a WLAN support ERP-OFDM efficiently then ERP attribute is enabled. On this context, the values of time slot and minimum contention window based on the two approach of WLAN operation. These are basic service set (BSS) and independent basic service set (IBSS). Table 2 shows the timing parameters of 802.11g and 802.11b standard.

Table 2. Timing parameters: 802.11g and 802.11b standard

Timing parameter	IEEE 802.11b	IEEE 802.11g
DSSS-Slot Time	20µs	9µs/20µs
DSSS-CCA Time	15µs	15µs
DSSS-Rx Tx Turnaround Time	9µs	2µs
DSSS-SIFS Time	10µs	16µs
DSSS-Preamble Length	72*	96bits
DSSS-PLCP Header Length	48	40bits
DSSS-PLCP Data Rate	2Mbps^{+}*	6Mbps
Initial Contention Window	31	15

*short preamble mechanism, $^{+}$Preamble: 1Mbps

2.3 The Distributed Coordination Function (DCF) of 802.11g MAC Protocol

In wireless LAN environment, Doufexi et al. [11] explain that, in the same transmission data rates, IEEE 802.11g covers about two times of the 802.11a network coverage. The IEEE 802.11 DCF [12] of MAC protocol utilizes the carrier sense multiple access with collision avoidance (CSMA/CA) method. Before sending a frame, the station first checks the channel status that it is free or not, detects a DIFS (Distributed Inter Frame Space) interval and then delivers a data frame if there is no other transmission in the progress. If frame is received correctly, after the SIFS (Short Inter Frame Space) interval, the receiving station sends an ACK frame. For reducing the chance of collision, the station senses the medium through randomized multiple of a time slot in between 0 to (CW-1), corresponding to the current contention window (CW). If the station detects the medium is still busy, it pauses the decrement of time counter. An exponential back-off mechanism is used to adjust the size of a CW. If the successful transmission attempt, the CW is equal to minimum contention window, CW_{min} and CW is doubles up to the maximum value of contention window, CW_{max}, if it does not receive an ACK for its frame. To avoid the hidden terminal problem [13], the transmitting station has two options that is either directly transmit the data packet or transmit a short RTS (Request- To- Send) frame with CTS (Clear- To- Send) frame. The basic access mechanism and RTS/CTS mechanism of IEEE 802.11 [14] is illustrated in figure 1.

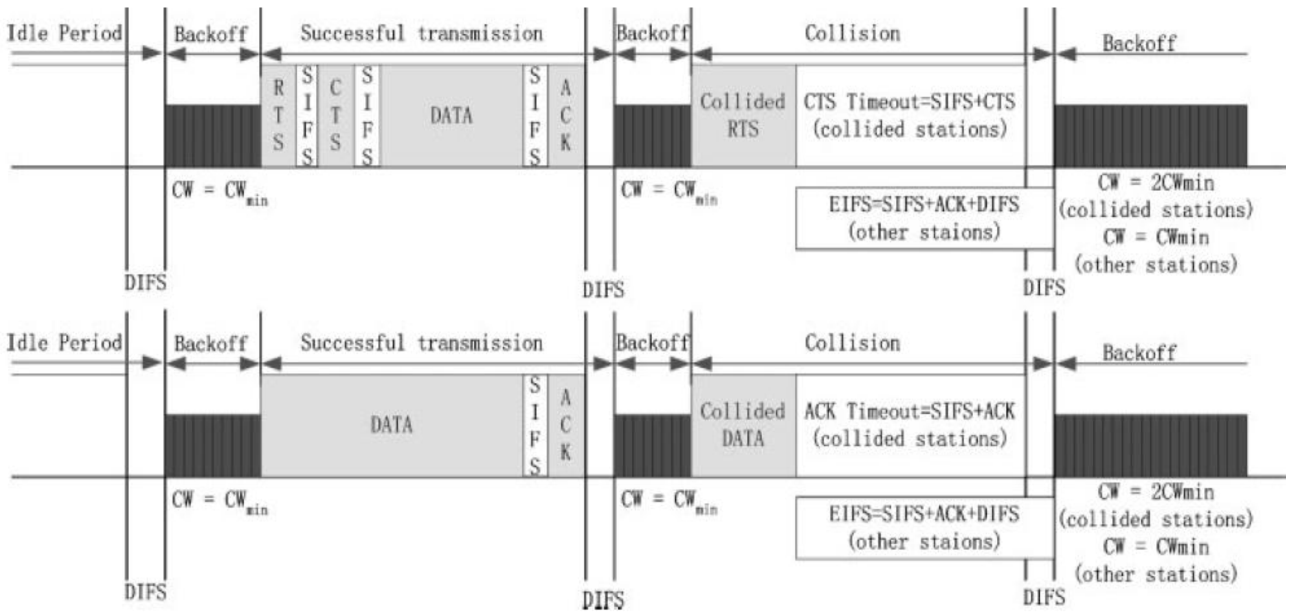


Figure 1: RTS/CTS mechanism and basic access mechanism of IEEE 802.11.

2.4 Protection Mechanism

For transmitting data frames efficiently, the stations in an IEEE 802.11g network uses between 14 different data rates and four different physical layers. Due to this, an interoperability problem arises by the physical layers. By employing different modulation techniques, IEEE 802.11g performs at the data rates which does not sustain by IEEE 802.11b. This results the interference cause by IEEE 802.11b between the transmitted packets of 802.11g stations and produces undesired performance degradation [15]. For different communication scenarios, physical layer parameters are summarized as table 3.

Table 3. Physical layer parameters for different communication scenarios

Communication	Preamble	Slot Time	CW_{min}
ERP-ERP	ERP-OFDM	20μs	31
ERP-non-ERP/S	Short	20μs	31
ERP-non-ERP/L	Long	20μs	31
Non-ERP/S-non-ERP/S	Short	20μs	31
Non-ERP/S-non-ERP/L	Long	20μs	31
Non-ERP/L-non-ERP/L	Long	20μs	31
All ERP	ERP-OFDM	9μs	15

When the access point senses that the network is associated with the both type of stations, then a protection mechanism is recommended. The IEEE 802.11g standard described two protection mechanisms, known as RTS-CTS and CTS-to-Self. RTS/CTS mechanism is used to protect the transmitted OFDM frames. By employing the ERP-DSSS physical layer, all RTS and CTS frames are transmitted essentially during ERP and non-ERP stations exist together, according to IEEE 802.11g.When all stations are capable of detecting an OFDM transmission, then RTS/CTS mechanism is not required, if only ERP stations are available in the network. In order to reduce collisions introduced by the DSSS/OFDM interoperability problem, the IEEE 802.11g standard defines the CTS-to-Self protection mechanism. The hidden terminal problem cannot handle effectively by CTS-to-Self mechanism because some other stations may not detect the CTS frame.

3. PERFORMANCE AND CHARACTERSTICS

The new physical layer can operate at a faster 9μs slot time, hence it is a wastage of time to operate at slower 20μs slot time of IEEE 802.11b standard. To reduce unnecessary collisions produced by DSSS/OFDM interoperability problem between data frames, the IEEE 802.11g standard designed the protection mechanism. According to M. J. Ho [16] report, the throughput of IEEE 802.11g devices reduces more than 30% as compared to pure 802.11g network along the longer slot time together with overhead.

Data rate, throughput, range and compatibility vary due to the differences in frequency, modulation schemes, and number of data rates.

3.1 Data Rates

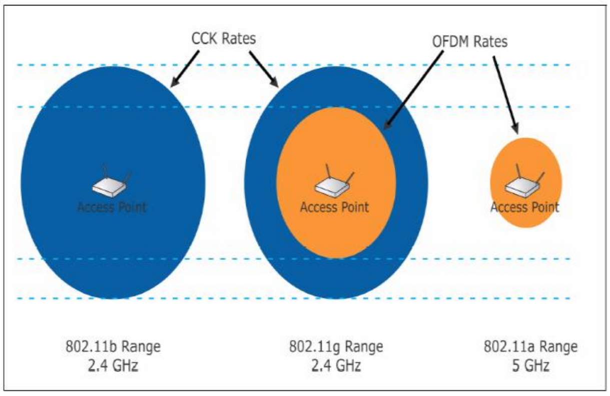
For providing communication at the best possible speed, the 802.11 standard technologies support multiple data rates. When number of users increases then the average data rate will be decreases smoothly, this results the degradation [17]. The IEEE 802.11g offers data rates up to 54Mbps by employing OFDM modulation technique and provides backward compatibility with the IEEE 802.11b. 16 QAM and 64 QAM modulations are required for higher data rates. By using mandatory data rates, the IEEE 802.11g standard accommodates best performance [18]. Table 4 shows the data rate specification for IEEE 802.11g.

Table 4. Data Rates Specification for IEEE 802.11g

Data Rate	Modula-tion Scheme	Coding Rate	Coded bits per Carrier (N_{BPSC})	Coded bits per OFDM symbol	Data bits per OFDM symbol
6 Mbps	BPSK	1/ 2	1	48	24
9 Mbps	BPSK	3/ 4	1	48	36
12 Mbps	QPSK	1/ 2	2	96	48
18 Mbps	QPSK	3/ 4	2	96	72
24 Mbps	16 QAM	1/ 2	4	192	96
36 Mbps	16 QAM	3/ 4	4	192	144
48 Mbps	64 QAM	2/ 3	6	288	192
54 Mbps	64 QAM	3/ 4	6	288	216

3.2 Range and Compatibility

Data rates provided by the 802.11 based devices will be reduced as the distance from the access point increases. Figure 2 shows the relative range of IEEE 802.11b, IEEE 802.11g and IEEE 802.11a devices.



. **Figure 2: Relative range of 802.11b, 802.11g and 802.11a Devices**

The 802.11g and 802.11 b standards have same propagation characteristics because both operate at 2.4 GHz frequency band. Therefore, implementations provide approximately the same maximum range at the same data rate. The IEEE 802.11a provide restricted range as compare to the rang of IEEE 802.11b and IEEE 802.11g devices because 5GHz radio signals do not propagate as well as 2.4GHz radio signals. The IEEE 802.11g uses the same CCK modulation as IEEE 802.11g for backward compatibility. To achieve better throughput at a given distance, the IEEE 802.11g uses OFDM modulation.

3.3 Throughput

Due to the access method overhead, environment and network composition, the throughput is not same as the data rate for networking system. The throughput of the faster station reduces by the rate of slower station due to a larger time taken by a station to transmit a data frame at a smaller bit rate; as a result the channel time utilized for the transmission of fast stations will be decreases [19].

In a uniform WLAN environment, the IEEE 802.11g provides best performance, when 802.11g access point (AP) communicates only with 802.11g clients. By using Transmission Control Protocol (TCP), the data rate within 75 feet is 54Mbps and the throughput is 22-24 Mbps in these environments. For IEEE 802.11 environment, maximum expected throughput is summarized in table 5.

Table 5. IEEE 802.11: Expected maximum Throughput

Dis-tance (Feet)	802.11 b (Mb/s)	802.11 a (Mb/s)	802.11 g (Mb/s)	802.11g Mixed Envir-oment with CTS-to-Self (Mb/s)	802.11g Mixed Enviro-nment with RTS/ CTS (Mb/s)
10	5.8	24.7	24.7	14.7	11.8
50	5.8	19.8	24.7	14.7	11.8
100	5.8	12.4	19.8	12.7	10.6
150	5.8	4.9	12.4	9.1	8.0
200	3.7	0	4.9	4.2	4.1
250	1.6	0	1.6	1.6	1.6
300	0.9	0	0.9	0.9	0.9

4. CONCLUSIONS

The main attraction of IEEE 802.11g is the provision of four different physical layers which support the data rate of IEEE 802.11a and provide backward compatibility with old IEEE 802.11 and IEEE 802.11b standards. This paper concludes the new features and performance characteristics of IEEE 802.11g standard in high data rate WLAN settings. In high data rate WLAN, the IEEE 802.11g is one of the most widely accepted standard which provide improve capacity. According to the user demands, the IEEE 802.11g provides the accurate combine characteristics with increased speed to 802.11g clients whereas the access point of IEEE 802.11g support existing IEEE 802.11b clients automatically.

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