ABSTRACT

In present scenario 802.11n is one of the fastest standards which is widely popular. It provides a theoretical maximum of 450 megabits per second (Mbps), with a typical throughput of 100Mbps. As we know, there is high demand for higher speed due to an increasing of high definition (HD) video on smart phone usage and home entertainment. As 802.11n is not able to provide the required speed needed for these uses, thus there is need for technologies which can meet the requirement. IEEE 802.11ad is one of such standards which meet the requirement needed for the above. IEEE 802.11ad standard operates at 60 GHz frequency, promise to deliver from 1 to 7 Gbps. 60 GHz band is one of the largest unlicensed bandwidth with availability of at least 5 GHz of continuous bandwidth worldwide. In this paper we have tested the IEEE 802.11ad system model Bits Error Rate (BER) for different modulation technique under several coding scheme for both Single Carrier and Multi Carriers. In this model the modulation technique mainly used are Binary Phase Shift Keying (BPSK), Quaternary Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (QAM), 64-Quadrature Amplitude Modulation (QAM) and the coding scheme used is Low Density Parity Check (LDPC) code with different code rate.

Keywords: IEEE 802.11ad, 60 GHz, Wireless local area network (WLAN), Long term evolution (LTE), Orthogonal Frequency Division Multiplexing (OFDM).

1. INTRODUCTION

Nowadays, gigabit wireless networking technologies are quite hot issues in academia and industry [1][2]. Initially, SiBEAM Inc. (acquired by Silicon Image Corporation) realized this technology in the Millimeter Wave (mmWave) frequency band named as Wireless HD at the Wireless HD consortium [3][4]. After checking the possibility of this technology for uncompressed high definition (HD) video streaming, two IEEE standards are composed, i.e., IEEE 802.15.3c [5] and IEEE 802.11ad [6] Very High Throughput (VHT). Now, IEEE 802.15.3c standardization is completed and the specification is available. IEEE 802.11ad VHT is currently draft 4.0 and the standardization will be completed soon.

There are several standards of Wi-Fi technology. Wireless communication that is widely used today operates either in 2.4 or 5 GHz frequency, for example, IEEE 802.11a/b/g/n. The data rate of these standards is in the range of 54-100 Mbps. However, there has been an increasing demand for higher data rate transmission because of a growing of high definition (HD) technology. Wireless communication system operating at 60 GHz [1] frequency band is introduced to support higher data rate transmission. There are five standards of 60 GHz wireless communication; IEEE 802.15.3c, ECMA-387, WirelessHD, IEEE 802.11ad, and Wireless Gigabit Alliance (WiGig) [7]. These four standards have different specification, maximum data rate, remarks, and supporting company. Nevertheless, their goal is similar, that is to enable Giga bit per second (Gbps) and higher communications over distances up to 10 meters WiGig currently cooperates with IEEE 802.11ad group to enable wireless local area network (WLAN) operation in the 60 GHz band. 60 GHz frequency band or millimeter-wave (mm-wave) wireless system promise to give data rate from 1 Gbps up to 7 Gbps, which is about 10 times faster than today wireless system. The large available spectrum surrounding 60 GHz frequency has ability to support high data rate. This is one of the largest unlicensed bandwidth provides at least 5 GHz of continuous bandwidth worldwide. However, 60 GHz system is difficult to implement. There are several challenges exist.
The major problem is that 60 GHz frequency suffers significantly from path loss. From this reason, the system is suitable in an indoor environment or a short distance transmission. The wireless video network shown on Figure 1, has three type of devices: video sink (HD display), video sources (set top box and mobile device) and devices that can perform both tasks (laptop).

![Fig. 1: Wireless video network example](image)

The major reasons for using 60 GHz frequency [8] band compared to the other frequency band at the mmWave frequency band are as follows:

- The most important attractive factor of 60 GHz mmWave wireless systems is the extremely broad bandwidth. As shown in Fig. 1, the wireless systems can use around 2.16 GHz for each channel and they can use four sub-channels, concurrently. As explained in Fig. 1, uncompressed HD video streaming can be realized if the system can get more than 1.5 Gbps, thus, 60 GHz mmWave systems can realize this new attractive concept in this new frequency band.

![Fig.2. Frequency plan for 60 GHz millimeter wave](image)

- For all countries in the world, 57 - 66 GHz frequency band is assigned as unlicensed. It means that everybody can use this frequency band for free [1]. In addition, 60 GHz mmWave transmitter and receiver antennas do not need to be re-designed for each country because the reserved mmWave frequency band area is same all the countries in the world. Thus, once consumer electronics companies or chipset vendors design only one antenna, it can be used for all countries (For the other frequency bands, each country has its own regulation for specific frequencies. Thus, the electronics companies need to design antennas for each country, separately.) [2].
2. SYSTEM MODEL

This example simulates BER/FER performance of 802.11ad signal under SISO AWGN channel. Here the output signal from WLAN_11ad_Source is the 1x-sampled complex baseband signals.

Here the incoming bits are scrambled and then encoded with LDPC or RS code depending on the MCS selected. After coding, Interleaver operates on the coded signal, which is fetch to the Constellation Mapping, then OFDM is applied to the signal for Multi-Carrier, which is applied to Inverse Fast Fourier Transform (IFFT) and at last the CP(Cyclic Prefix) is added to the signal. After RF conversion to 60 GHz the signal is passing through the channel. At the Receiver End of 802.11ad, the received signal is first down converted, then removal of Cyclic Prefix is processed, after removal of CP the Fast Fourier Transform (FFT) is applied, and the signal is pass through OFDM demodulator for Multi-Carrier. Then Constellation Demapping is done on the signal, which is De-Interleaved and at last the Decoding and Descrambling is applied to the signal to get the required bits.

Before RF conversion the signal is oversampled in the filter models with some oversample ratio. The pre-configured filter types for both SC and OFDM modulation are as follows

- **SC:** Raised Cosine filter with Symbol Rate = 1.76e9 Hz, Roll Off (Alpha) = 0.5
- **OFDM:** Flat Top filter with Pass Freq = 2.5e9 Hz, Order = 96

2.1 IEEE 802.11.ad

IEEE 802.11ad was formed in January 2009 as an amendment to the existing IEEE 802.11-2007. This amendment defines standardized modifications to both the 802.11 PHY and the 802.11 MAC to enable very high-throughput operation in the 60 GHz frequency band [9]. This amendment specifies a maximum MAC service access point throughput of at least 1 Gbps while maintaining the network architecture of the 802.11 system as well as backward compatibility with the 802.11 management plane. In addition, IEEE 802.11ad is intended to define a mechanism for fast session transfer between 2.4/5 GHz and 60 GHz operation bands, while coexisting with other systems in the 60 GHz band such as IEEE 802.15.3c and ECMA-378. IEEE 802.11ad is an amendment to the 802.11 WLAN standard which enables up to 7 Gbps data rates in the unlicensed and globally available 60 GHz band. With much more spectrum available than the 2.4 GHz and 5 GHz bands, the 60 GHz band has wider channels, enabling higher data rates over short distances (1m – 10m). Primary 802.11ad applications will be to remove wires between High-Definition multimedia, computer displays, I/O and peripheral, peer to peer data synchronization and higher speed LAN.

A shared MAC layer with existing 802.11 networks enables session switching between 802.11 networks operating in the 2.4 GHz, 5 GHz and 60 GHz bands, resulting in uninterrupted wireless data communications. The 802.11ad MAC layer has been extended to include beam forming support and address the 60 GHz specific aspects of channel access, synchronization, association, and authentication.

The design and integration of 802.11ad[10] devices present challenges in tackling 10 times higher frequencies and 100 times wider modulation bandwidths than previous WLAN standards. A mix of modulation technologies (both Single Carrier and OFDM) and the use of active directional antennae further complicate matters.

At IEEE 802.11ad [11], the task group presented that Rapp model (for amplitude distortion) and Rapp model (for phase distortion) are suitable for modeling the nonlinearity of power amplifier [12]. For more details, following equation presents the amplitude distortion (modeled by Rapp model), i.e.

\[ F_{\text{AM/PM}}^R (\alpha) = \gamma_1 \frac{\alpha}{(1 + \gamma_2^2 \gamma_2^2)} \]

where \( \gamma_1 = 19, \gamma_2 = 0.81, \) and \( \alpha \) stand for the small gain signal, the smoothness factor, and the saturation level, respectively. In addition, the phase distortion (modeled by modified Rapp) is formulated as follows:

\[ F_{\text{AM/PM}}^P (\alpha) = \frac{\alpha \gamma_1}{(1 + \gamma_2^2 \gamma_2^2)} \]
where \( a = -48000 \), \( b = 0:123 \), \( g_1 = 3:8 \), and \( g_2 = 3:7 \).

2.2 Modulation Scheme

Fig. 4. Constellation maps for modulations: (a) \( \pi/2 \) BPSK, (b) \( \pi/2 \) QPSK, (c) \( \pi/2 \) 8-PSK, (d) \( \pi/2 \) 16-QAM

(1) \( \pi/2 \) BPSK

Figure 4(a) shows the signal constellation of \( \pi/2 \) BPSK signals. The \( \pi/2 \) BPSK (\( \pi/2 \) BPSK) modulation is a binary phase modulation with \( \pi/2 \) phase shift counter-clockwise. The \( \pi/2 \) BPSK modulator consists of a \( \pi/2 \) chip level rotator to conduct the phase rotation. The outputs of two pulse shaping filters are fed into a quadrature modulator and generate the modulated outputs. The diagram of the modulator is shown in Figure 4[13].

Fig. 5. \( \pi/2 \) BPSK Modulator

(2) \( \pi/2 \) QPSK

The \( \pi/2 \) QPSK constellation diagram is shown in Figure 4(b). QPSK encodes 2 bits into one symbol. The \( \pi/2 \) shift is employed to obtain a simple implementation aligning with the \( \pi/2 \) BPSK

(3) \( \pi/2 \) 8PSK

The \( \pi/2 \) 8-PSK constellation diagram is shown in Figure 4(c), equally spaced on a circle of radius one, representing eight phases. The \( \pi/2 \) 8-PSK shall encode 3 bits per symbol. The same \( \pi/2 \) rotation is performed as for BPSK and QPSK modulation. Gray encoding should be employed in the mapping of \( \pi/2 \) 8-PSK. The normalization factor, \( K_{MOD} \) is 1.

(4) \( \pi/2 \) 16-QAM

The \( \pi/2 \) 16-QAM constellation diagram is shown in Figure 4(d). The serial bit stream shall be divided into groups of four bits with input bit \( c_0 \) being the earliest in the stream. The \( \pi/2 \) rotation is performed in the same manner as for other three types of modulations. The normalization factor for \( \pi/2 \) 16-QAM constellation is \( 1/\sqrt{10} \).
2.3 Forward Error Correction

The forward error correction codes proposed for 11ad system are Reed-Solomon Block (RS) codes and Low Density Parity Check (LDPC) codes.

- Reed-Solomon block codes in GF($2^8$)

The generator polynomial for the systematic RS codes is defined as:

$$g(x) = \prod_{n=1}^{16} (x + \alpha^n) \quad \text{......... (iii)}$$

where $\alpha = 0x02$ is a root of the binary primitive polynomial $p(x) = 1 + x^2 + x^3 + x^4 + x^8$. As notation, the element $M = b_7x^7 + b_6x^6 + b_5x^5 + b_4x^4 + b_3x^3 + b_2x^2 + b_1x + b_0$, has the binary representation $b_7b_6b_5b_4b_3b_2b_1b_0$, where $b_7$ is the msb and $b_0$ is the LSB.

The first 239 information octets $i = (i_{238}, i_{237}, \ldots, i_0)$ are used to generate the codeword octets $c = (i_{238}, i_{237}, \ldots, i_0, p_{15}, p_{14}, \ldots, p_0)$ by computing the parity check polynomial (remainder polynomial) $p(x)$:

$$p(x) = \prod_{n=0}^{15} i_n x^n = \text{Mod} \left[ x^{16} i(x), g(x) \right] \quad \text{.........(iv)}$$

where $i(x)$ is the information polynomial:

$$i(x) = \prod_{n=0}^{238} t_n x^n \quad \text{......... (v)}$$

and $p_n, n = 0, \ldots, 15$, and $i_n, n = 0, \ldots, 238$, are elements of GF($2^8$). The shortened RS code is defined as $(L_{inf} + 16, L_{inf})$, where $L_{inf}$ indicates length of transmitted information bits. 239-$L_{inf}$ zero elements are appended to the incoming $L_{inf}$ octet message as follows:

$$t_n = \begin{cases} 
  t_n & n = 0, \ldots, L_{inf} - 1, \\
  0 & n = L_{inf}, \ldots, 238 
\end{cases} \quad \text{.........(vi)}$$

The inserted zero elements are not transmitted. For RS (23, 7) $L_{inf} = 17$ while for RS (56, 40) $L_{inf} = 40$.

The RS (255,239) is used for PLCP CMS data field. The shortened version of RS (255, 239) codes, i.e., the RS (23, 7) is used in the PLCP SIGNAL, respectively.

- Low Density Parity Check Codes (LDPC)

Low density parity check codes [14] [15] are proposed as a FEC codes to provide a high performance error correction. The LDPC codes selected are irregular LDPC codes with three code rates: ½, ¾, and 7/8. The corresponding parameters of selected codes are described in Table 1.

The proposed LDPC codes are systematic codes. Every $k$ information data are encoded to a codeword with length $n$. The codeword $c$ can be represented as

$$c = [i_1, i_2, \ldots, i_k, p_1, \ldots, p_{(n-k)}] \quad \text{......... (vii)}$$

Where $i_j$ stands for $j$th information bit and $p_j$ stands for $j$th parity bit. The LDPC codes can be decoded using the parity check matrix $H$, where $H$ is an $(n, k) \times n$. 

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Table 1. Parameters of Selected LDPC Codes

<table>
<thead>
<tr>
<th>FEC rate, $R_{\text{FEC}}$</th>
<th>Information block length (bits), $L_{\text{inf}}$</th>
<th>Codeword block length (bits), $L_{\text{FEC}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>336</td>
<td>672</td>
</tr>
<tr>
<td>3/4</td>
<td>504</td>
<td>672</td>
</tr>
<tr>
<td>7/8</td>
<td>588</td>
<td>672</td>
</tr>
</tbody>
</table>

The parity check matrix of three proposed LDPC codes are with the dimension of 336×672, 168×672, and 84×672. Each of the parity check matrices can be partitioned into square sub blocks (sub matrices) of size $z \times z$ ($z=21$). These sub matrices are either cyclic-permutation of the identity matrix $I^i$ or null (all-zero) sub matrices. $I^i$ indicates the sub matrix obtained by cyclically shifting columns to the left by $i$ elements.

3. RESULTS

BER Performance of the System

In Fig. 5.a the BER performance of the system is given when the system is in Single Carrier mode. Here the coding used is ¾-LDPC with a Sample Rate of 1.76 GHz for which Raised Cosine Filter is used. As we can see in the graph that with the change in the modulation from $\pi/2$-BPSK (blue) to $\pi/2$-QPSK (red) and then to $\pi/2$-QAM16 (black) the system performance has degraded. The BER performance of $\pi/2$-BPSK is best among the three modulations.

In Fig. 5.b the BER performance of the system is given when the system is in Multi Carrier mode. Here the coding used is ¾-LDPC with a Sample Rate of 2.64 GHz for which Flat Top Filter is used. As we can see in the graph that with the change in the modulation from QPSK (blue) to 16-QAM (red) and then to 64-QAM16 (black) the system performance has degraded. The BER performance of QPSK is best among the three modulations.
In Fig.6.a the BER performance of the system is given when the system is in Single Carrier mode. Here the Modulation used is $\pi/2$-QAM16 with a Sample Rate of 1.76 GHz for which Raised Cosine Filter is used. As we can see in the graph that for most of the SNR values the system behave alike for all three coding but as the SNR increases there is variation in the plot, and we can easily say that with the change in the coding from 1/2-LDPC (blue) to 5/8-LDPC (red) and then to 3/4-LDPC (black) the system performance has degraded. The BER performance of 1/2-LDPC is best among the three coding.

In Fig.6.b the BER performance of the system is given when the system is in Multi Carrier mode. Here the Modulation used is QPSK with a Sample Rate of 2.64 GHz for which Flat Top Filter is used. As we can see in the graph that for most of the SNR values the system behave alike for all three coding but as the SNR increases there is variation in the plot, and we can easily say that with the change in the coding from 1/2-LDPC (blue) to 5/8-LDPC (red) and then to 3/4-LDPC (black) the system performance has degraded. The BER performance of 1/2-LDPC is best among the three coding.

4. CONCLUSION

This paper has presented the performance evaluation of both Single Carrier and Multi Carrier for different type of modulation scheme and coding used in IEEE 802.11ad. All the results are derived for SISO under the typical channel model in IEEE 802.11ad. The results demonstrates that, when the coding was same and modulation was different for Single Carrier and Multi Carrier, $\pi/2$-BPSK gives the best performance in Single Carrier and QPSK gives the best performance in Multi Carrier. And when the modulation was same and coding was different for Single Carrier and Multi Carrier, 1/2-LDPC gives the best performance in Single Carrier and in Multi Carrier.

In the future plane, the author wants to develop Mi-Fi using Long term evolution (LTE) and IEEE 802.11ad.
5. REFERENCES


