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HaLow Wi-Fi Performance in Multi-users and Channels Environment with MATLAB Simulink

Fatima Faydhe Al-Azzawi
Institute of technology, Middle technical university (MTU), Baghdad, Iraq
Fatima_faydy1981@mtu.edu.iq
Majida Saud Ibrahim
Institute of technology, Middle technical university (MTU), Baghdad, Iraq
Fatima_faydy1981@mtu.edu.iq
Kamal Y. Kamal
Institute of technology, Middle technical university (MTU), Baghdad, Iraq
Fatima_faydy1981@mtu.edu.iq

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Abstract

HaLow Wi-Fi (IEEE 802.11ah) wireless networking standard. Compared to 2.4 GHz and 5 GHz-based conventional Wi-Fi networks, it leverages 900 MHz frequencies license-exempt for enabling networks with a more extended range. Lower energy usage makes it possible to build extensive networks of sensors or stations that work together to communicate signals, which is another advantage. In this paper, the IEEE 802.11ah Wi-Fi system was designed and implemented using MATLAB Simulink and tested under multi-users and channels environment in terms of Spectrum analyzer and constellation Diagram where 4 users, 2 MHz and 4 MHz channels bandwidth used to perfume the test also the power of coarse synchronization, fine synchronization and initial channel estimation, to make Wi-Fi networks with a more excellent range possible were illustrated in space-time stream, M-PSK modulation transceiver Simulink is implemented by MATLAB and tested under AWGN, Rayliegh, Rician fading channels in term of BER.

Keywords: HaLow Wi-Fi, IEEE 802.11ah, IEEE 802.11 Wi-Fi

1. Introduction

HaLow Wi-Fi, also known as IEEE 802.11ah, is a wireless communication standard that operates in the sub-gigahertz frequency range. It is designed for low-power, long-range communication and is particularly well-suited for use in the Internet of Things (IoT) and innovative home applications [1], [2].

HaLow Wi-Fi uses a narrower bandwidth than traditional Wi-Fi, which allows it to penetrate walls and other obstacles more effectively, making it ideal for use in large buildings and other complex environments. It also uses a lower power consumption, which extends the battery life of IoT devices and reduces the need for frequent battery replacement [3], [4].

HaLow Wi-Fi supports M-PSK and M-QAM (M-ary Quadrature Amplitude Modulation) modulation techniques, allowing it to transmit data at higher rates over long distances. This makes it possible to support various applications, including remote monitoring, control, and automation of devices in the home, office, and industrial environments [5], [6].

One of the critical features of HaLow Wi-Fi is its ability to support a large number of devices simultaneously. This is achieved through multiple access points, which can be deployed in a mesh network to provide full coverage over a wide area [7], [8].

HaLow Wi-Fi also includes advanced security features to protect the data's privacy and integrity. This includes support for WPA3 encryption, which provides high security for Wi-Fi networks [9], [10].

HaLow Wi-Fi (IEEE 802.11ah) is a wireless communication standard for low-power, long-range communication in the sub-gigahertz frequency range. It supports many devices simultaneously, making it well-suited for IoT and innovative home applications. It also includes advanced security features to protect the data's privacy and integrity [11], [12].

Synchronization is a critical function of the 802.11ah standard as it enables the accurate transmission and reception of data frames between devices. To achieve synchronization, two methods are used:

(1) Coarse synchronization is a critical step in the synchronization process of the IEEE 802.11ah standard. It involves aligning the clocks of devices within a network to within a few hundred microseconds [13, 14]. This level of synchronization is critical in enabling the accurate transmission and reception of data frames. Coarse synchronization is achieved through a preamble, a sequence of known symbols transmitted at the beginning of a frame. The preamble estimates the channel delay and frequency offset between the transmitter and receiver. The receiver then adjusts its clock to align with the transmitter's clock [15], [16]. The estimation of the channel delay is performed through the use of a Time Domain Synchronization (TDS) sequence. In contrast, the frequency offset estimation uses a Frequency Domain Synchronization (FDS) sequence. Once the devices' clocks are aligned, fine synchronization can be performed, which involves adjusting the clock to within a few nanoseconds. Fine synchronization is achieved through data symbols, which are transmitted at a known rate, and the phase difference between the received and expected data symbols is used to adjust the clock. Coarse synchronization is a critical step in the synchronization process, as it allows devices to align their clocks within a few hundred microseconds. This level of synchronization is essential for the accurate transmission and reception of data frames, particularly in networks with high data rates. Using known preambles and synchronization sequences enables devices to estimate the channel delay and frequency offset, allowing them to adjust their clocks accordingly [17], [18].

(2) Fine synchronization is a critical process in the IEEE 802.11ah standard, which enables the alignment of the devices' clocks within a few nanoseconds. This high level of synchronization is essential in enabling accurate data transmission and reception between devices, particularly in networks with high data rates. In IEEE 802.11ah, fine synchronization is performed after coarse synchronization, which aligns the devices' clocks within a few hundred microseconds. The delicate synchronization process involves using data symbols transmitted at a known rate to adjust the phase of the received data symbols relative to the expected data symbols. To achieve fine synchronization, the receiver first determines the timing offset between the received and expected data symbols [19], [20]. This timing offset is then used to adjust the phase of the received data symbols, aligning them with the expected data symbols. Adjusting the phase of the received data symbols is performed using a feedback loop that measures the difference between the received and expected data symbols and applies a correction to the phase of the received data symbols. The accuracy of the delicate synchronization process is critical in enabling high data rates, particularly in networks that use high-order modulation schemes such as 256-QAM or 1024-QAM. High-order modulation schemes enable higher data rates but require more accurate synchronization to ensure the data symbols are correctly aligned. In summary, fine synchronization is a critical process in IEEE 802.11ah, enabling the alignment of the devices' clocks within a few nanoseconds. Using data symbols and a feedback loop enables the adjustment of the phase of the received data symbols, ensuring accurate data transmission and reception between devices. The accuracy of the delicate synchronization process is essential in networks with high data rates and high-order modulation schemes [21], [22].

Initial channel estimation is an essential process in the IEEE 802.11ah standard, which is used to establish the initial conditions of the wireless channel. The accuracy of the initial channel estimation process is critical in enabling accurate data transmission and reception between devices. In IEEE 802.11ah, initial channel estimation is performed during the synchronization phase, divided into two parts: coarse and fine. Coarse synchronization is responsible for aligning the clocks of devices to within a few hundred microseconds, while fine synchronization is responsible for aligning the phase of the received data symbols [23], [24].

The initial channel estimation process in IEEE 802.11ah is performed using a training sequence transmitted from the transmitter to the receiver. The training sequence consists of a known symbol sequence that enables the receiver to estimate the channel response. The receiver uses the training sequence to estimate the channel response, including the wireless channel's amplitude, phase, and delay. The receiver then uses this information to perform channel equalization, compensating for the channel response's distortion. The accuracy of the initial channel estimation process is critical in enabling high data rates, particularly in networks that use high-order modulation schemes such as 256-QAM or 1024-QAM. High-order modulation schemes enable higher data rates but require more accurate channel estimation to ensure the data symbols are correctly received[25], [26].

In this paper, IEEE 802.11 Wi-Fi system is designed and implemented using MATLAB Simulink and tested under multi-users and channels environment in terms of Spectrum analyzer and constellation Diagram where 4 users, 2 MHz and 4 MHz channels bandwidth used to perfume the test also the power of coarse synchronization, fine synchronization and initial channel estimation, the receiver de-mapped to determine parameters of transmission those users relevant to which illustrated in the space-time stream.[9], [10]

2. HaLow Wi-Fi (IEEE 802.11)

HaLow Wi-Fi (IEEE 802.11) wireless transmitter and receiver block diagrams are illustrated in Figures 1 and 2, respectively [29].

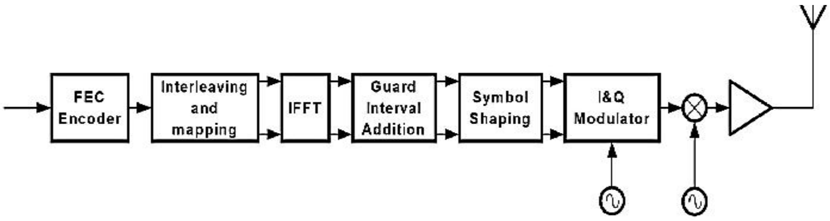

Figure 1. IEEE 802.11 ah Transmitter

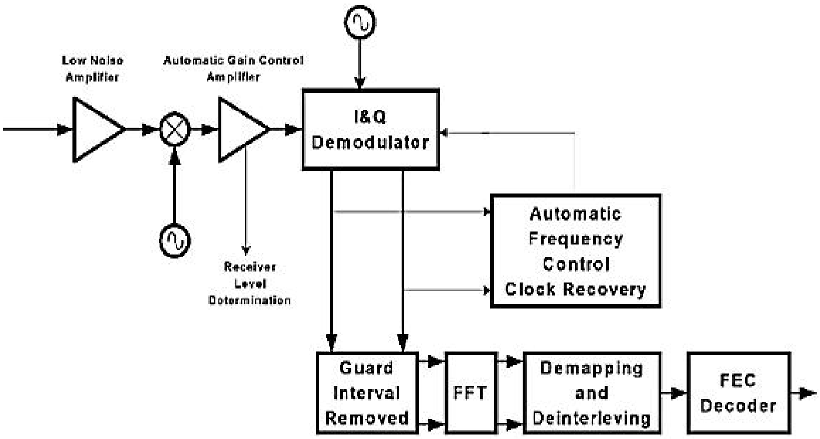

Figure 2. IEEE 802.11 ah Receiver

2.1 FEC Encoder

Forward error correction (FEC) or channel coding reduces data transmission errors through noisy communication or unreliable channels used in telecommunication, information theory, and coding theory. The main concept is that the sender redundantly encrypts the message, typically using an ECC.[11], [12]

2.2 Interleaving and Mapping

While mapping, interleaving, a method for enhancing the robustness of forward error correction about burst faults forwarding mapping Port, a network address translation (NAT) program used in computer networking that switches requests of communication address and number port while through a network gateway, the packets are passing, like a firewall or a router. By remapping the IP address and number port of the internal host, this technique is most frequently used to make services on a host located on a protected or masqueraded (internal) network access to hosts on the other side of the gateway (external network).

2.3 IFFT

To effectively synthesize frequencies that equally divide the transforming period or "frame," utilize an inverse fast Fourier transform. It is also possible to manufacture sinusoids of any frequency using a series of overlapping frames and the inverse fast Fourier transform by carefully considering the DFT frequency-domain representation.[13]

2.4 Guard Interval Addition

Guard intervals are used in communications to prevent interference or other overlapping transmissions between different broadcasts. These broadcasts may be made by the same user or by separate users (as in TDMA) (as in OFDM). The IEEE 802.11 OFDM standard symbol guard interval is 0.8 s. [14]

2.5 Symbol Shaping

Shaping of Pulse is changing the transmitted pulse waveform in telecommunications electronics. The purpose of this station is to modify

The transmission's suitability for using communication channels by reducing the transmission's adequate bandwidth. The inter-symbol interference brought on by the channel can be controlled using filters of the pulses transmitted in this manner. Pulse shaping is necessary for RF transmission to fit the signal inside the appropriate frequency range.[15]

2.6 Modulation

In HaLow Wi-Fi, M-PSK modulation transmits data over the airwaves. This is achieved by changing the phase of the carrier wave to represent the digital 1s and 0s that make up the data signal. HaLow Wi-Fi uses different levels of M-PSK modulation to encode different data symbols.

The M-PSK modulation used in HaLow Wi-Fi is beneficial for long-range communication because it is less susceptible to noise and interference than other modulation techniques. This is because M-PSK modulation can be configured to use a more significant number of symbols per bit, which provides better immunity to noise and interference.

HaLow Wi-Fi with M-PSK modulation provides high data security by using a sophisticated error correction scheme. The error correction scheme allows the receiver to detect and correct errors in the data signal, even in the presence of significant noise and interference. HaLow Wi-Fi with M-PSK modulation is an advanced wireless communication technology that provides high data rates over long distances with low power consumption. M-PSK modulation provides better noise immunity and high data security through sophisticated error correction techniques. This technology has many potential applications in the Internet of Things (IoT) and other long-range wireless communication systems [30].

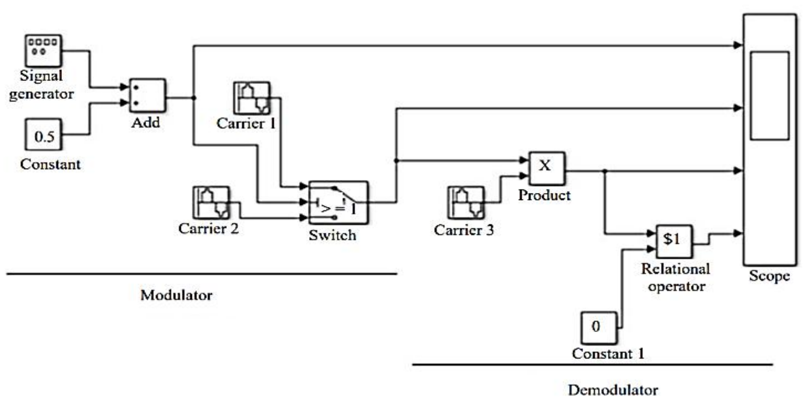

Figure 3. M-PSK System in MATLAB Simulink

M-PSK is used as shown in Figure 3, where simulation blocks of the M-PSK modulator and demodulator are illustrated; Figure 4 shows PSK system signals, information, PSK, after generation and recovered input signal. M-PSK tested under AWGN, Rayleigh, and Rician channels, as shown in Figure 5. [16], [30]

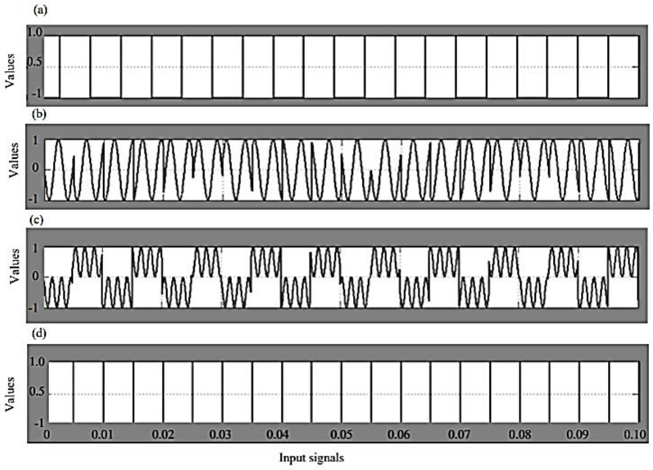

Figure 4. PSK System Signals: a. Information; b. PSK; c. After Generation; d. Recovered Input Signal

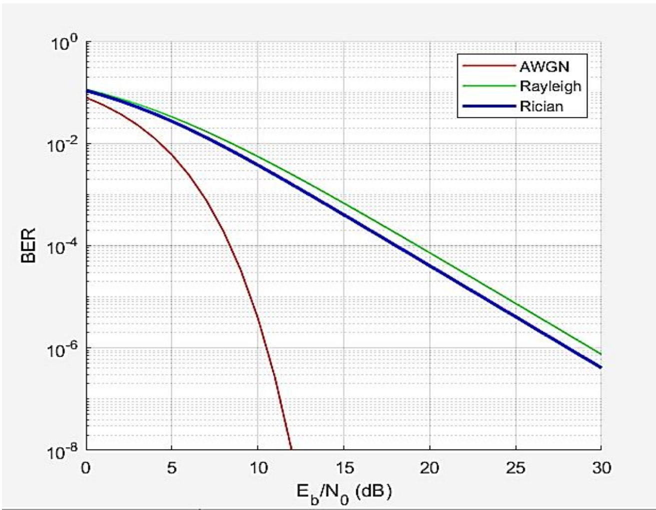

Figure 5. PSK Modulation in Multi Channels Environments

Three modes are specified by the 802.11ah standard: Applications requiring low data rates should use the 1 MHz mode (S1G 1M). This model includes a more extended preamble and the MCS10 coding and modulation scheme to increase robustness. BPSK 1/2 rate with two repetitions is MCS10. The Short Training Field (STF) is increased by 3 dB when MCS10 enables packet detection [2]. The entire Physical Protocol Data Unit (PPDU) is beamformed in this mode.[17]

When using a 2, 4, 8, or 16 MHz channel bandwidth for single- or multi-user broadcasts, the greater or equal to MHz long preamble mode (S1G LONG) is employed. It resembles an 802.11ac VHT PPDU, comprising a beam-changeable and omnidirectional portion. When using a 2, 4, 8, or 16 MHz channel bandwidth for single-user transmissions, the greater or equal to 2 MHz short preamble mode (S1G SHORT) is employed. The whole PPDU is beamformed in this mode.[18]

The preamble Type setting provides a few extra data header strings to help check for mistakes in Wi-Fi data transfer. Short Preamble Type transmits the error redundancy check with fewer and shorter data strings, which makes it significantly faster. Long Preamble Type employs longer data strings for improved error checks.

Preamble Type extended settings are typically required in two different situations.

(1) Needing Preamble Type Long to connect to older devices. Preamble Type long is required to connect if you have an older wireless card because Preamble Type short is only possible with more recent technology.

(2) Using Wi-Fi in a location with weak or strong signal interference. Preamble Type is a function or tool that, by default, aids in data transmission error checks. A long preamble type can increase transmission if the wireless signals are weak.

The 802.11ah lengthy preamble supports both single-user and multi-user transmissions. The omnidirectional section and beam-changeable portion make up the lengthy preamble PPDU. All users receive without beamforming the omnidirectional component. It is a parting to three fields [31], [32], [33]:

(1) The short training field STF serves as a rudimentary synchronizing mechanism.

(2) The first long training field LTF1 is utilized for initial channel estimate and fine synchronization.

(3) The signalling A field SIG-A determines transmission characteristics relevant to all users, which the receiver decodes.

Each user's beam formation can be applied to the beam-changeable section. There are four fields in it:

(1) The beamformed short training field D-STF, used at the receiver's automatic gain control.

(2) The beamformed long training fields D-LTF were used to estimate the channel in the MIMO system.

(3) The signalling B field SIG-B. The SIG-B transmits the MCS for each user in a multi-user transmission. The preamble's omnidirectional SIG-A field serves as the MCS signal in a single-user transmission. Therefore, The SIG-B symbol transmitted during a single-user transmission is an identical replication of the initial D-LTF. This repetition enhances the channel estimate.

(4) The data field Data, the user data payload of which carries.

3. Simulation Results

Implementing IEEE 802.11ah standard in MATLAB requires a thorough understanding of the standard and signal processing techniques. Here is a general outline of the MATLAB code structure for the standard:

(1) Generate the training sequence waveform with known symbols transmitted from the transmitter to the receiver.

(2) Add channel effects to the transmitted signal to simulate the wireless channel, including path loss, shadowing, and multi-path fading.

(3) Perform coarse synchronization using a correlation-based method to align the devices' clocks within a few hundred microseconds.

(4) Perform fine synchronization using a maximum likelihood estimation method to align the phase of the received data symbols.

(5) Perform initial channel estimation using the received training symbols and a least-squares method to estimate the channel response, including amplitude, phase, and delay.

(6) Perform channel equalization using the estimated channel response to compensate for the distortion of the channel response.

(7) Demodulate and decode the received data symbols using the demodulation and decoding techniques specified in the IEEE 802.11ah standard.

It's important to note that implementing the standard in MATLAB requires a significant amount of time and effort due to the complexity of the standard and the signal-processing techniques involved. Additionally, the system's performance may be affected by several factors, such as interference, multi-path fading, and noise. Therefore, additional signal processing techniques may be required to mitigate their effects.

IEEE 802.11 Wi-Fi system design and implemented using MATLAB R2022a Simulink and tested under multi-users and channels environment in terms of Spectrum analyzer and constellation Diagram where 4 users, 2 MHz (as shown in figure 6, 9, 10, 11) and 16 MHz (as shown in figure 12, 13, 14, 15) channels bandwidth used to perfume the test also the power of coarse synchronization, fine synchronization and initial channel estimation as shown in figure 7, to determine transmission parameters that are relevant to all users, the receiver decodes. Were illustrated in the space-time stream, as shown in Figure 8.

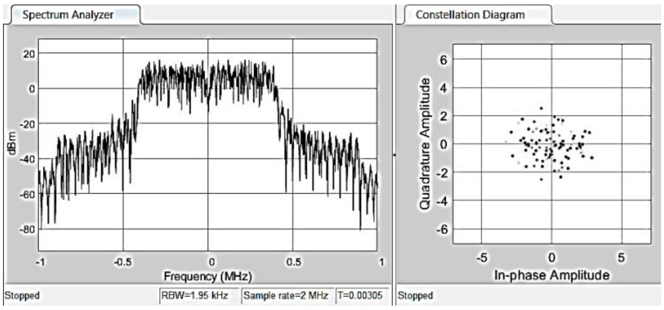

Figure 6. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 2MHz and One User

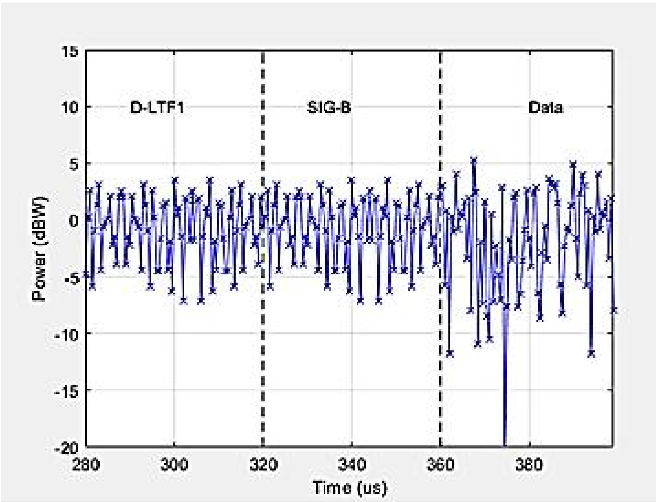

Figure 7. Power of 2 MHz Single User SU Long Preamble Physical Protocol Data Unit PPDU

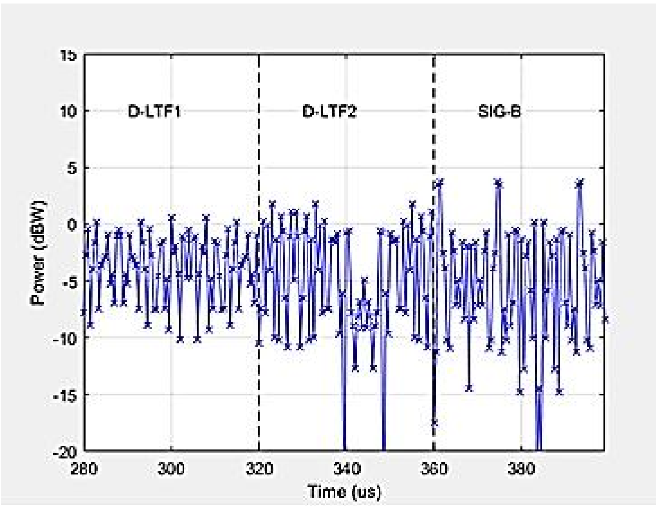

Figure 8. Power of 2 MHz Multi-User MU Long Preamble Physical Protocol Data Unit PPDU

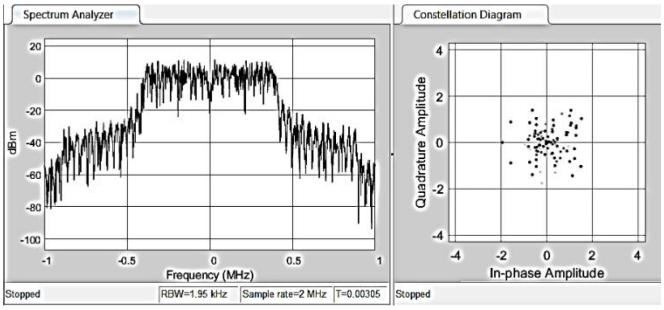

Figure 9. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 2MHz and Two Users

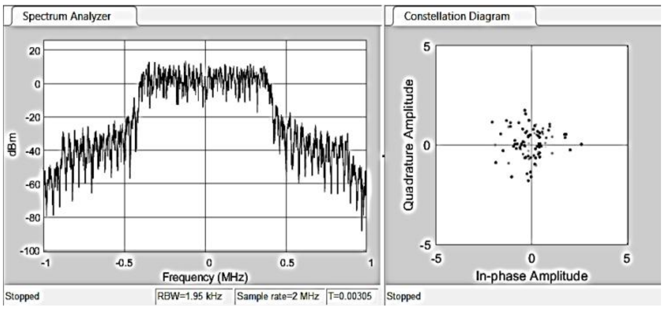

Figure 10. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 2MHz and Three Users

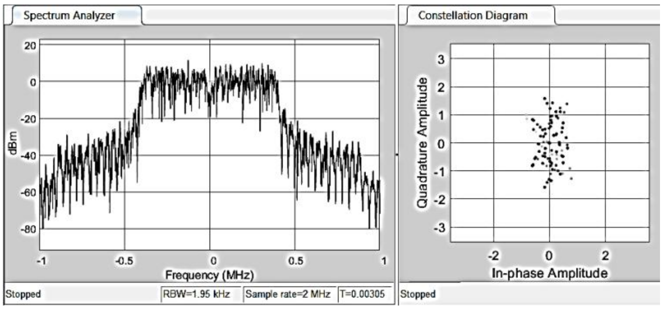

Figure 11. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 2MHz and Four Users

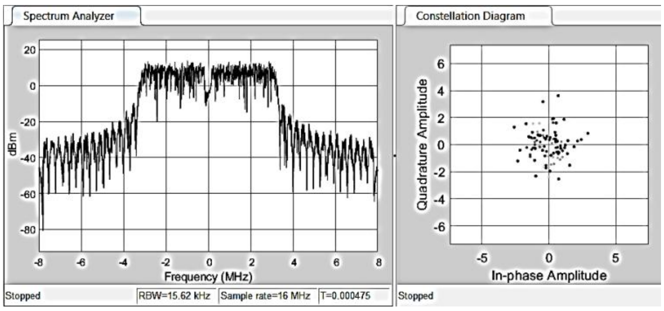

Figure 12. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 16 MHz and One User

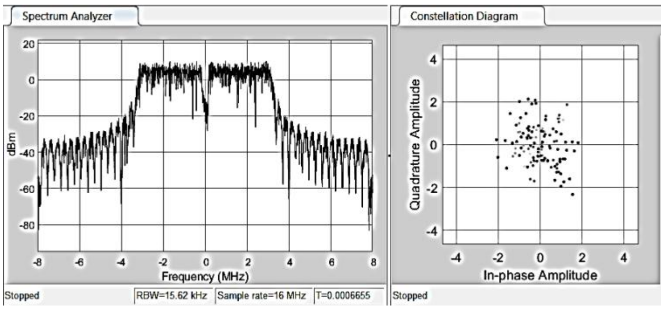

Figure 13. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 16 MHz and Two Users

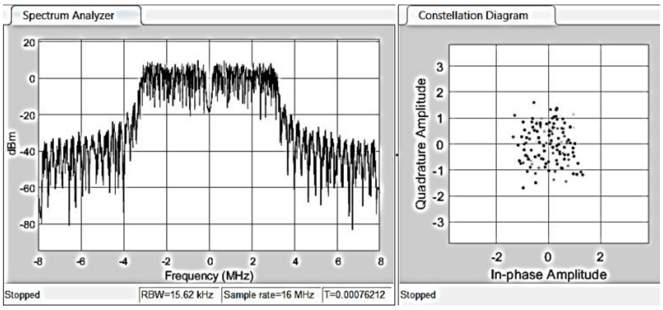

Figure 14. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 16 MHz and Three User

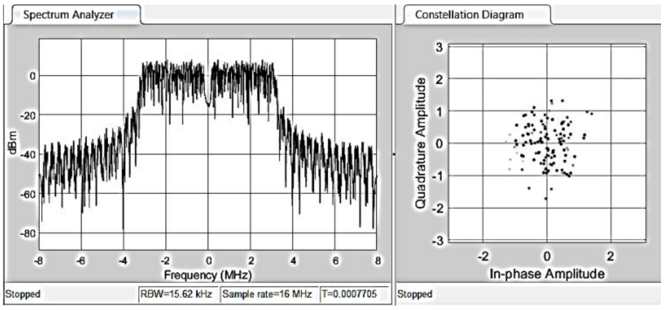

Figure 15. IEEE 802.11ah Spectrum and Constellation Diagram where BW= 16 MHz and Four User

4. Conclusion

In this paper, the IEEE 802.11ah Wi-Fi system was designed and implemented using MATLAB Simulink and tested under multi-users and channels environment in terms of Spectrum analyzer and constellation Diagram where 4 users, 2 MHz and 16 MHz channels bandwidth used to perfume the test also the power of coarse synchronization, fine synchronization and initial channel estimation, To determine parameters of transmission that are specific to all users, the receiver decodes. Were illustrated in a space-time stream. Lower energy usage makes it possible to build vast networks of stations or sensors that work together to share signals. Where power at D-LTF1 and SIG-B reaches 4 dBW while data symbols reach 5 dBW in the single user environment, D-LTF1 and D-LTF2 reach 1 and 2.5 dBW, respectively, while SIG-B equal to 4.5 dBW in the multi-user environment, from above results IEEE 802.11ah Wi-Fi system has the added benefit of higher data rates and more comprehensive coverage range. It can be implemented under High Bit rate Modulation approaches like M-QAM for improving performance.

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