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Analysis and Performance Evaluation of Worldwide Interoperability for Microwave Access (WiMAX) Communication System

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Abstract
This paper focuses on the analysis and performance evaluation of worldwide interoperability for Microwave Access using MATLAB based approach. In the 5th generation of wireless mobile telecommunication network, the request for an elevated data rate with access to portable customers is overwhelming. Mobile worldwide interoperability for Microwave Access (WiMAX) becomes a favorable alternative that is intelligently developed than Wireless Fidelity (Wi-Fi). This technology makes use of Orthogonal Frequency Division Multiple Access (OFDMA) for its two-way communications to enhance the system performance in fading environments. Furthermore, in this paper, whenever the user stays away from the base station with a particular SNR, a poor quality of signal can be achieved due to degradation. Also, whenever the user stays closer to the base station for the same SNR, a good quality of signal can be maintained. The results obtained shows that OFDMA has the most increased capacity and best performance according to the values of BER and SNR.

Keywords: MATLAB, Orthogonal Frequency Division Multiplex, Signal-to-Noise Ratio, Bit-Error-Rate, WiMAX.

1. Introduction

There is a big problem when it comes to the provision of ubiquitous broadband and guaranteeing of Quality of Service (QoS). As such, due to the nature of WiMAX technology, it is proposed to offer the capacity of bringing the underlying internet connection needed to service local area networks with the view of providing several levels of QoS (Patidar *et.al.,* 2012). WiMAX can be recorded as a standard wireless technology which is based on IEEE 802.16 broadband wireless access metropolitan area technology. It is an air-interface standard for microwave and millimeter-wave band of IEEE 802.16 Standard technique of 2009 (Pareit *et.al.,* 2012). WiMAX also known as IEEE Wireless Metropolitan Area Network, (WMAN) can provide an effective interoperability broadband wireless access method under the MAN of a point to multipoint multi-vendor environment. Wireless Mesh Networks (WMNs) are widely envisioned to be a key technology to improve the capacity and coverage for wireless broadband access services at reasonable costs in areas where wired communication infrastructure can be too costly to install (Siris *et.al.,* 2008)

The WiMAX Forum which is an industry-led, non-profit organization was established in June 2001 to promote and certify wireless broadband equipment based on two standards, which are the IEEE 802.16 and European Telecommunications Standards Institute High Performance Metropolitan Area Networks (ETSI HiperMAN) (Villegas-Garcia *et.al.,* 2015). WiMAX which is an air interface standard in connection with the frequency ranges of microwave and millimeter wave has its main purpose as to provide a broadband wireless access approach which can be interoperated effectively in the environment of multiple network providers with "one-point to multi-point" in the metropolitan area network (Amit *et.al.,* 2010). The working frequency of WiMAX ranges from 2 – 66GHz (2 – 11GHz for IEEE 802.16 standard; 10 – 66GHz for IEEE 802.16a standard) and the channel bandwidth can be adjusted flexibly within the range of 1.5 – 20MHz, which is favorable for fully utilizing the frequency spectrum resources in the distributed channel bandwidth (Flores *et.al.,* 2013).

WiMAX adopts micro-cells with the maximum coverage up to 50km in the 20MHz channel bandwidth and supports a sharing data transmission rate as high as 70Mbit/s. Multi-sector technology can be used to expand the system capacity with each sector supporting more than 60 users or hundreds of family users of E1/T1 simultaneously (Houet *et.al.,* 2018). WiMAX adopts various advanced technologies to realize the Non Line of Sight (NLOS) and On Non Line of Sight (ONLOS) transmission, such as Orthogonal Frequency Division multiplexing (OFDM), receiving-transmitting diversity, adaptive modulation, which greatly improve the efficiency of wireless transmission in cities (Ruchin *et.al.,* 2018). The physical layer supports two kinds of wireless duplex multiple access Time Division Duplex, (TDD) and Frequency Division Duplex (FDD) to adapt to the requirements of telecommunication system. It supports Single Carrier (SC), OFDM (256 points), and OFDMA (2048 points), which can be selected flexibly as needed (Traganitis *et.al.,* 2015).

The physical layer can change subject to the performance of transmission channel. The modulation mode and parameters of physical layer such as, modulation parameters, forward error control parameter, power level, and polarization method can be adjusted dynamically to guarantee good transmission quality (Jianyun *et.al.,* 2019). The main idea of OFDM technology is that the given frequency domain is divided into orthogonal sub-channels, with each sub-channel using a sub-carrier to modulate and each sub-carrier transmits in parallel with the base station providing a connection between the subscriber station and the core network. It generally uses a sector/beam antenna or umbrella antenna, which provides flexible arrangement and configuration of sub-channels, upgrades and expands the network based on the conditions of users (Ecclesine *et.al.,* 2013). The subscriber station is a base station which provides the repeater connection between the base station and the user equipment terminal and it generally uses a beam antenna installed on the roof. The dynamic adaptive modulation mode of the signal is used between base station and subscriber station (Kumar *et.al.,* 2013).

2.0 Material and methods

The materials used in this paper are Simulink, MATLAB Function block, Digital Signal Processing System Toolbox and Communications System Toolbox. To simplify the implementation of WiMAX model as well as the perspective of processor capabilities, the restriction of two Mobile Stations (MS) and 1024 Fast Fourier Transform (FFT) size was implemented. With respect to the functionality of WiMAX model shown in figure 1, out of 1024 frequency carriers, 720 subcarriers were used to carry user data, the rest were reserved for pilots and guards. To properly allocate the data carriers to different Mobile Station (MS), the standard organizes 720 subcarriers into 30 sub-channels in which each of these sub-channels contains 24 subcarriers. The standard (IEEE 802.16 Standard) allows frequency resources in sub-channels to be dynamically allocated to Mobile Station. This indicates that when this model is running, Base Station (BS) can dynamically change the sub-channel allocation to MS1 and MS2. In one burst, sub-channels 0-5 are allocated to MS1 and sub-channels 6-25 are allocated to MS2. In another burst, the allocation can become 2-10 and 15-25 respectively. When more sub-channels are allocated to one mobile station, more data can be transmitted to this mobile station in one burst. This dynamic change introduces variable-size signaling. The variable-size features of the WiMAX tools are shown in figure 1.

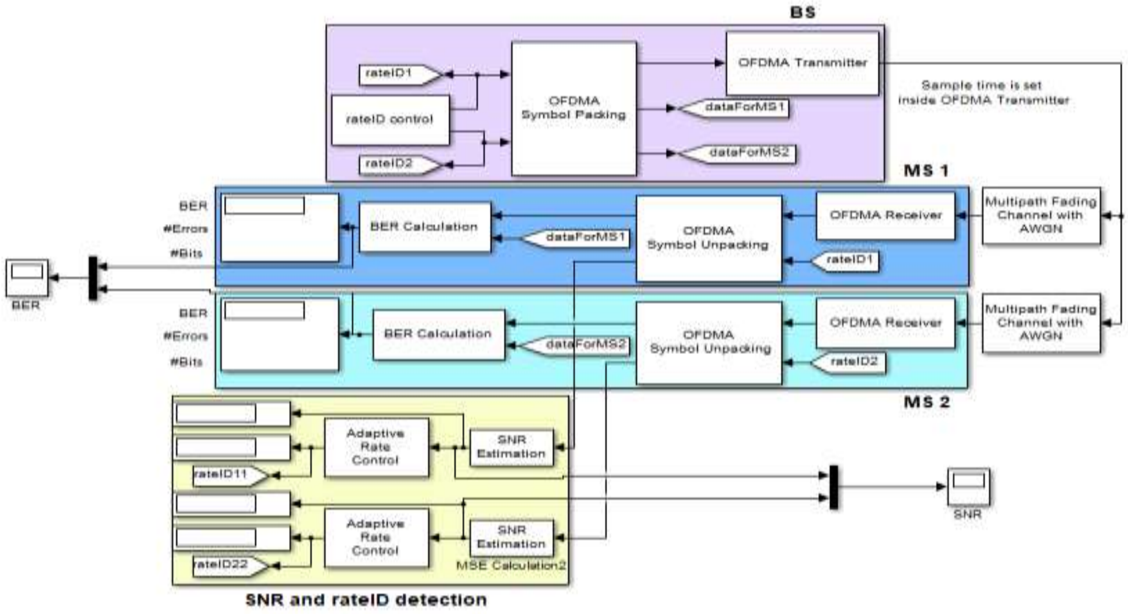

Figure 1: The SIMULINK Model of WiMAX

The OFDMA Symbol Packing Subsystem shown in Figure 2 is organized into five parts namely; the generate headers and user data, channel coding, allocate sub-channels, permutation and renumbering, add pilots and guards. These blocks generate data and packs them into OFDMA symbols. Mobile WiMAX is based on the modulation technique which is called Orthogonal Frequency Division Multiplexing Access (OFDMA). OFDMA has advantages in throughput, spectral efficiency, latency and advanced antenna support which make it a better technology. This modulation technique has been engaged in data providing systems over the phone lines and digital audio and wireless networking systems. In Frequency Division Multiplexing (FDM), there are multiple sub carriers within the same single channel, so the total data is divided between sub carriers in the channel. If the FDM system is using a set of sub carriers that are orthogonal to each other, an improved level of spectral efficiency can be accomplished; the use of orthogonal sub carriers will allow the sub carriers spectra to overlap this increasing the spectral efficiency. Each sub carrier carries one bit of information by its presence or absence in the output spectrum. The frequency of each sub carrier is picked to produce an orthogonal signal set and these frequencies are known at the receiver. OFDM is tolerant of multi path interference, a high peak data rate can be achieved by using higher order modulations such as 16QAM and 64QAM which improves the spectral efficiency of the system.

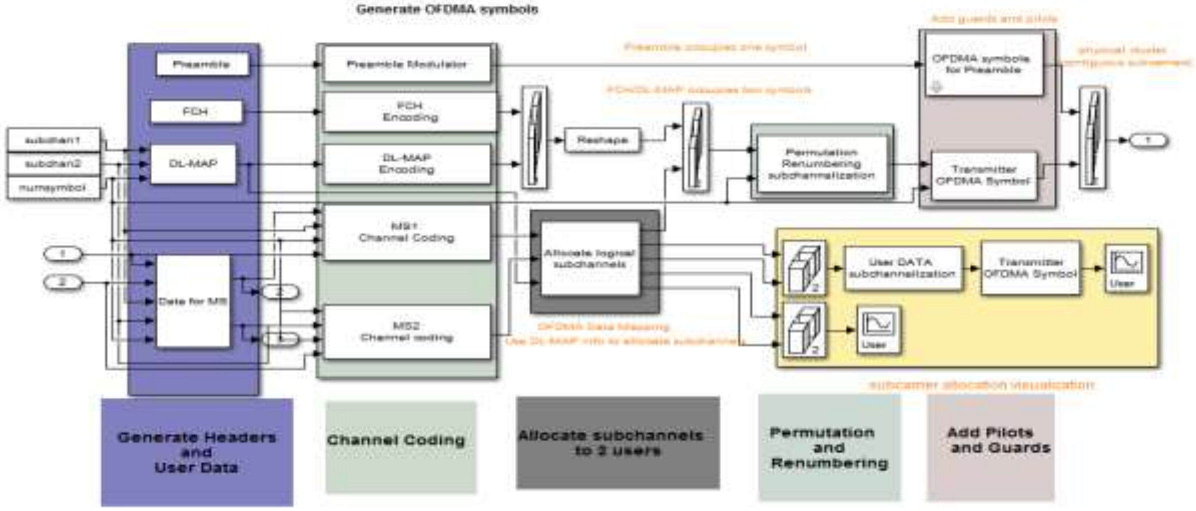

Figure 2: Packing Block of OFDM Symbol

2.1 Mathematical model

The serial data input is a sequence of samples occurring at interval T_s. The high rate serial input data is converted to column data which is of lower rate. The low-rate column data consists of M low-rate parallel streams in order to increase the symbol duration to $T = MT_s$. The low-rate streams are represented by the symbols: $b_m[k]$, $m = 0,$ 1, 2, …, $M-1,$ and $k =$ 1, 2, 3, where each stream is modulated onto different sub-carriers.

The orthogonal relationship between any two sub-carriers in a set is kept constant in order to avoid the Inter Channel Interference (ICI). Afterwards, the parallel streams are multiplexed and a Cyclic Prefix is induced so as to eliminate the effect of Inter Symbol Interference (ISI). The transmitted kth symbol, y(t) is obtained as shown in equation 1.

$$y(t)=\sum_{m=0}^{m-1} b_m[k]e^{j2\pi mt/T} \tag{1}$$

[Subject to the condition: $-G+kT \le t \le (k+1)T$]

Where; G = the length of the Guard Interval, $b_m[k]$ = m^{th} stream of data coming out as the kth symbol, $y(t)$ = the signal that is passed through the channel and modeled as the frequency selective fading channel.

The modeling of the channel can be realized by considering the tapped-delay line with time-varying coefficients and fixed tap spacing as shown in equation 2.

$$h(t,\tau)=\sum_{1=0}^{x+1} h_1(t)\delta(\tau-\tau_1) \tag{2}$$

Where $h_1(t)$ = the complex amplitude, τ_1 = the delay of the I^{th} path, $x+1$ = the total number of taps, and $h_1(t)$ = the determining factor employed to get the correlation function.

The received signal $r(t)$ is given in equation 3:

$$r(t)=\int_{-\infty}^{\infty} h_1(t,\tau)y(t-\tau)=\sum_{1=0}^{x+1} h_1(t)y(t-\tau_1)+n(t) \tag{3}$$

Where $1=0$, τ_1 = the maximum multipath delay spread and $n(t)$ = factor quantifying the background noise.

Channel estimation is applied to get the estimates of channel fading in each sub-carrier such that coherent detection is achieved. Let q be the sub-carrier index at the output of the OFDM demodulator in a WiMAX system and $s_{k,q}$ the output for the q^{th} sub-carrier in the k^{th} symbol interval. Since a wireless channel is primarily multipath, the transmitted signal reaches the receiver not by a single path but by a number of paths, either by reflection, scattering or diffraction. This multipath nature results in a phenomenon called fading. Assuming a mobile station is moving with a constant velocity, V, at an angle θ from the incoming signal direction, then the frequency shift or the Doppler shift is given in equation 4

$$f_D=\frac{V}{\lambda}Cos\theta \tag{4}$$

Where f_D = Doppler shift, V = Velocity, and λ = Wavelength

For a receiver moving along the ground at some constant velocity, V, $x(t)$ represent the transmitter signal, $y(d,t)$ represent the received signal at position, d, and $h(d,t)$ represent the channel impulse response which is dependent because all the multipath components being received by the mobile station will change if d is changed.

The multipath channel fading is realized as shown in equation 5

$$y(d,t)=x(t)\otimes h(d,t)=\int_{-\infty}^{\infty} x(\tau)h(d,t-\tau)d\tau \tag{5}$$

Where $y(d,t) =$ Convolution of $x(t)$ and $h(d,t)$, $y(d,t) =$ received signal at a location d of the mobile station at any time, t.

The Received signal at mobile station travelling with the velocity V is given in equation 6.

$$y(t) = \int_{-\infty}^{\infty} x(\tau)h(t,\tau)d\tau = x(t) \otimes h(t,\tau) \quad \ldots \quad (6)$$

Where $y(t)$ = Received signal at Mobile Station travelling with the velocity V, and located at a distance d, $x(t) =$ Transmitted signal convolved with $h(t,\tau)$, and $h(t,\tau) =$ IR for the multipath channel. (Rakesh *et.al.*,2012).

3.0 Results and Discussions

The simulation results consist in observing how the quality of the signal varies at the receiver side when it is affected by fading and the values of SNR is low. The principle used in this simulation is to transmit an original signal, modulate it, pass it through a Rayleigh fading channel and plot it at the receiver side. The simulation result was done such that the addition of SNR for users 1 and user 2 should not be below 50dB and the operation of the entire system was simulated with a total bandwidth of 5MHz. In the constellation diagram, the projection of the point on the X-axis indicates the peak amplitude of the in-phase component and the projection of the point on the Y-axis indicates the peak amplitude of the quadrature component. The length of the line (vector) that connects the point to the origin is the peak amplitude of the signal element (combination of the X and Y components) and the angle the line makes with the X axis is the phase of the signal element.

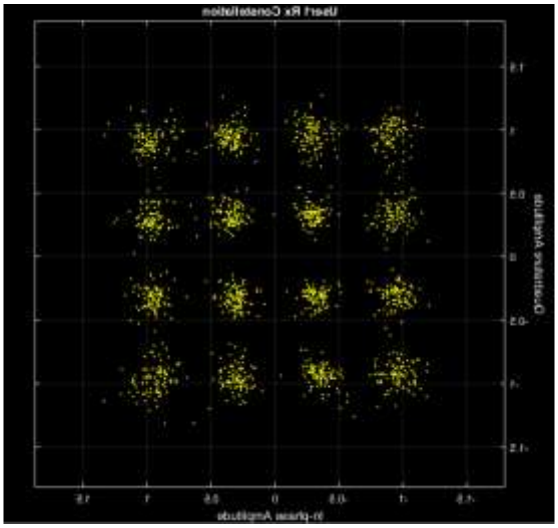

Figure 1: User 1 constellation plot for SNR=25dB.

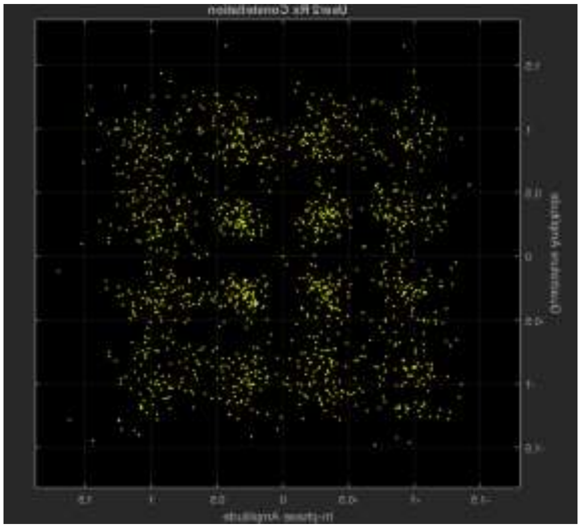

Figure 2: User 2 Constellation plot for SNR = 25dB

In figures 1 and 2, at equal SNR of 25dB for both users, it is observed that the quality of the signal for user 2 is poor as compared to user 1. This poor quality of signal is attributed to attenuation caused by fading since user 2 was further away from the base station. Also, user 1 maintains a good quality of signal and this user was closer to the base station. (Angelakis *et.al.*, 2011)

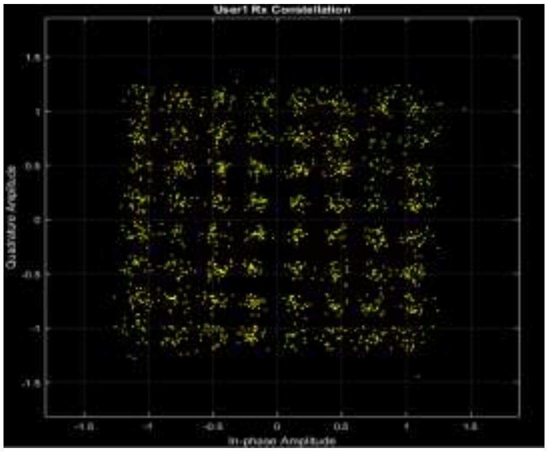

Figure 3: User 1 constellation plot for SNR=30dB

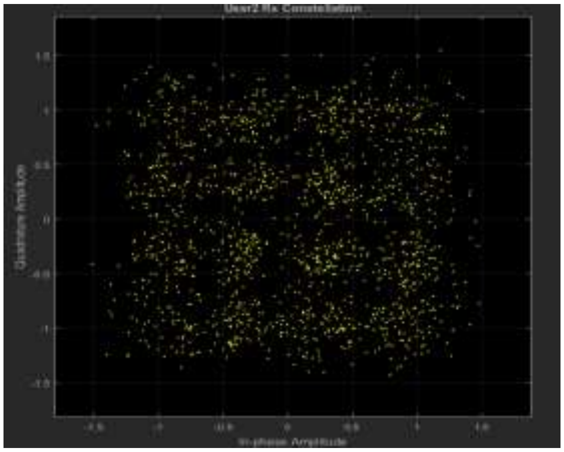

Figure 4: User 2 constellation plot for SNR=30dB

When the value of SNR increases to 30dB for user 1 and user 2, the signal quality of user 2 degraded while the signal quality of user 1 improved. This indicates that the quality of the signal decreases when the value of SNR decreases. In practical situations, solutions must be found to check whether the signal has reached its limitation point and must be attenuated or needs to be amplified. However, with the low value of SNR and BER, the intelligibility of the carrier is strongly affected especially in mobile communication where fading is much deeper than in other types of communications. (Masud *et.al.,* 2011)

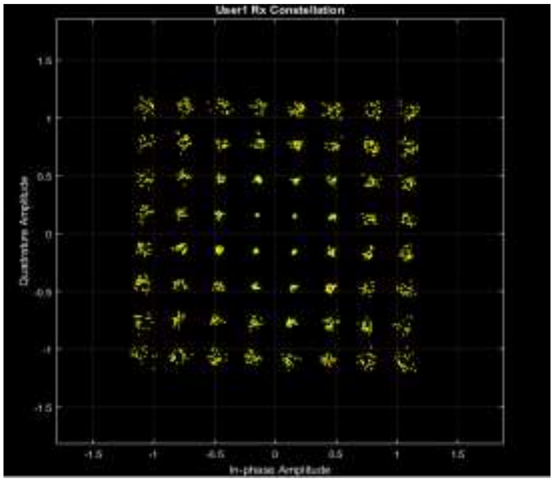

Fig. 5: User 1 Constellation plot for SNR=50dB

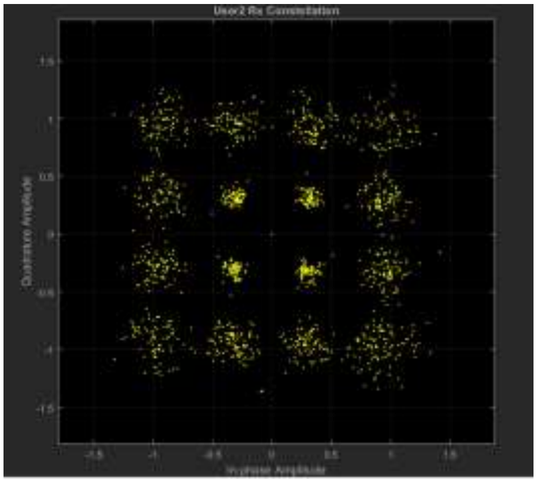

Fig 6: User 2 Constellation graph plot for SNR=50dB

In figures 5 and 6, when the values of SNR of both users were increased to 50dB, it can be observed that the scatter plot can be distinguished for both users but clearer in user 1 than in user 2, although for user 1, much difference is not noticed in the signal quality as compared to when the SNR was kept at 35dB.

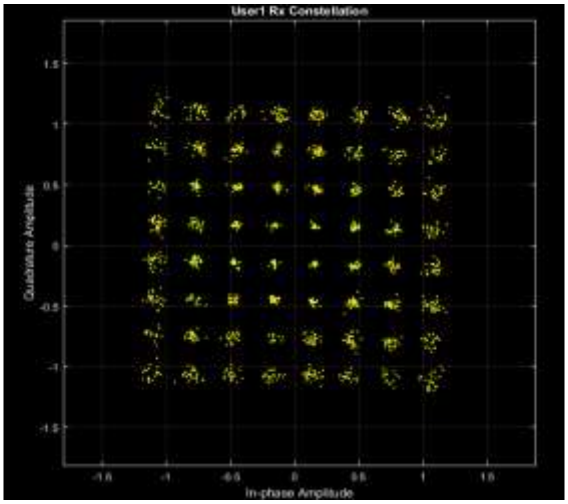

Fig. 7: User 1 Constellation plot for SNR=35dB

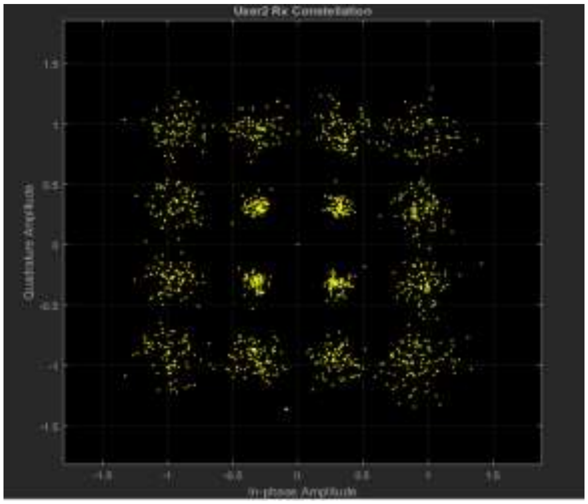

Fig. 8: User 2 Constellation plot for SNR=45dB

In figure 7, when the value of SNR was increased to 35dB, the scatter plot became clearer but in figure 8 when the signal was increased to 45dB, the scatter plot was not clear. This indicates that there was improvement in signal quality for user 1 and there was a drop in signal quality for user 2.

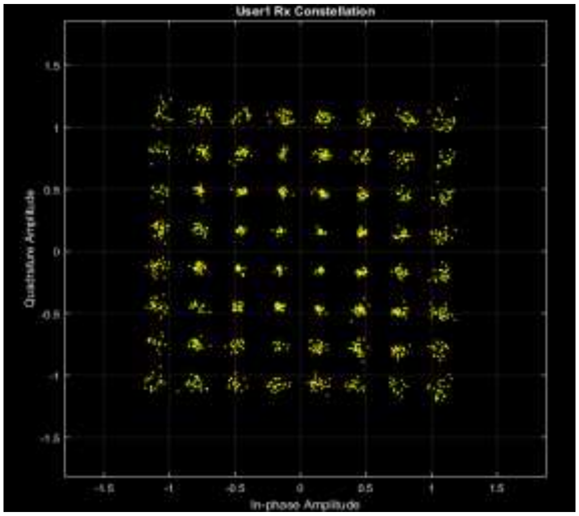

Figure 9: User 1 Constellation plot for SNR=35dB

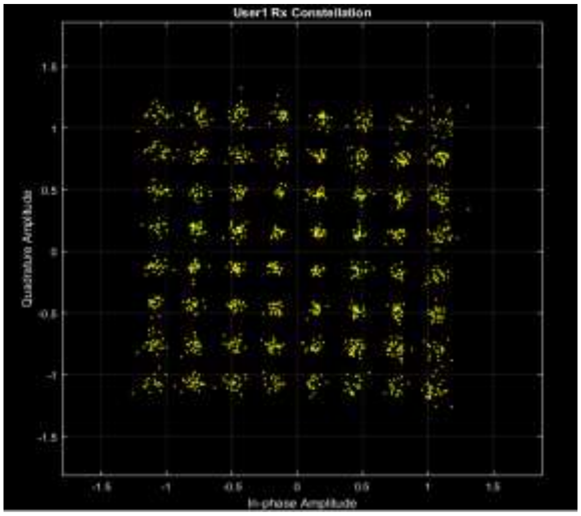

Fig. 10: User 2 Constellation plot for SNR=65dB

In the second part of the simulation, Bit Error Rate (BER) and Symbol Error Rate (SER) were computed by generating random bits to be transmitted, using gray code map to symbols of different modulations and mapping to closest symbol and adding all the errors at the receiver side. The results show that an acceptable value of BER/SER of (10^6) was obtained when the values of Energy Bit to Noise ratio or Energy Symbol to Noise Ratio are greater than 100dB.

4.0. Conclusion

During experiment, there is no distinction for the entire figure, due to the number of users being used at the time of simulation. The constellation diagrams entail that increasing the number of users does not expressly deform the packing as there is a stated number for each packing. However, increasing the number of users in a system does not go on infinitely, as there is a capacity to be accommodated by a system, depending on the distance of the receiving and transmitting antennas from a user. Therefore, an ideal system will have antennas with no losses and channeling medium with zero attenuation.

It becomes quite obvious that for a proper functionality of a system for N–mobile stations, the channel of the respective users is expected to operate in SNR’s different from each other, such that there is an optimum margin for each user to attain the best QoS for a definite SNR. This will assist in minimizing power losses being supplied to power the system. The number of mobile stations can also be increased for a system, by ensuring that the required SNR for the respective users is correctly allotted as this will ensure that the BER/SER is as well kept low and QoS constant.

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