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Experimental validation of 802.11A Transceiver with an Open-Source Software Defined Radio-Based Prototype

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***ABSTRCT** This paper presents an analysis and Frame Error Rate (FER) results for an experimental study on different channel conditions and performance of IEEE 802.11a transceiver. This paper concentrates on both physical layer (PHY) and Medium Access Control (MAC). GNU Radio is one of the best open source Software Defined Radio (SDR) used for packet-based transceiver systems. To analyse the system, a data was transmitted and received as packets and evaluated FER performance of the system in the presence of Additive White Gaussian Noise (AWGN) over Rayleigh and Rician distributed fading channels. The data recovered was stored in Packet Capture (PCAP) format which is used to investigate networks with common network protocol analyser software like Wireshark. For implementing this transceiver, we used IEEE 802.11 blocks in GNU Radio. This implementation and simulation results gave a confidence to move a step forward towards real-time validation.*

***Index Terms**: MAC layer, PHY layer, OFDM, SDR, GNU Radio, Channel Models, FER*

I. INTRODUCTION

In recent years, there is magnificent development in wireless technology in various aspects like devices, protocols and applications. Future wireless technology includes low energy consumption and high data rates for data heavy applications. overcrowding becomes an issue for commonly-accessed mobile bandwidths when there are a greater number of users. To process the contention inherent more flexible methods must be used in multiple access. To meet the necessities of expanding usage of number of devices, the current wireless communications standards are frequently emerging. One of the modern standard mobile phone technologies is Long-Term Evolution (LTE) [1] and to prototype and test the next generation technology many research projects are being conducted. The future technology is concentrating in increasing the Quality of Service (QoS), Security, Bandwidth and low cost of service.

which is less sensitive to frequency selective fading because it splits a high data rate modulating stream placing them onto many closely modulated narrowband adjacent subcarriers. OFDM is widely used in wireless communication systems, due to its resistance to Inter Symbol Interference (ISI) caused by difficult channel.

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Orthogonal Frequency Division Multiplexing (OFDM) is the most emerging technology to carry better communication system. This is a form of signal modulation In the next generation, performance of the wireless communication system increases depending on the Bit Error Rate (BER) and spectral efficiency, this can be achieved by using OFDM.This technology is extensively used in wireless communication systems, for example,3GPP Long Term Evolution (LTE) systems, IEEE 802.16d/e Wireless Metropolitan Area Networks (WiMAX), IEEE 802.11a/g/n Wireless Local Area Networks (WLAN)and terrestrial Digital Video Broadcasting (DVB-T) or digital broadcasting services like digital audio broadcasting (DAB) and more recently very high-speed digital subscriber line (VDSL) and internet access over copper wires like asymmetric digital subscriber line (ADSL).

To meet current and future demands, new technologies and protocols are to be tested and developed. For rapid prototyping and testing of communication system, Software defined radio (SDR) is a perfect solution. SDR provides a comprehensive radio communication platform, based on which new technology can be used through software update [2]. This leads to a large-scale reduction in expansion costs and enables the product to maintain technology development. The SDR platform can be set up with an open, standard, and programmable hardware platform, based on which the functions of the radio can be perceived by adding appropriate software modules.

GNU Radio is a most popular signal processing framework which is an open source. It is used as software for SDR based General-Purpose Processor (GPP) and implement signal processing on a GPP like a normal PC. It is used in several areas, such as military, amateur radio, industry, academia and government.

With the help of this GNU Radio, SDR based OFDM is developed and tested in various channel conditions. In this paper an IEEE 802.11a transceiver is developed and tested in different channel conditions. Both MAC layer and PHY layer are developed in this paper.

For testing the system, a known data was transmitted and received in different channel conditions and FER performance of the system was compared and analysed. Synchronization and channel estimation techniques are used at the receiver to recover the data.

The recovered data from the MAC layer in receiver section is also displayed using Wireshark connector. To observe the channel conditions constellation diagrams and the OFDM signal spectrums are also observed.

II. BACKGROUND

This section gives an overview of an IEEE 802.11a network withPHY and MAC layers. This standard allowshigher data transfer rates because the network operates in the 5 GHz medical, industrial, and scientific bands [3]. This frequency band requires no license and theoretically allows a maximum throughput of up to 54 Mbps. The standard defines protocols for thephysical (PHY) layer and MAC sublayer of the communications system (Fig.1).

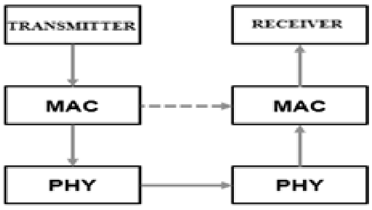

Fig. 1 IEEE 802.11a standard protocol.

A. MAC Sublayer

The MAC sublayer is used to control and manage access and distribution of packet transmissions through available channels. This protocol helps the LAN to use the available bandwidth effectively. Two access mechanisms are specified in IEEE 802.11: the contention-based Distributed Coordinator Function (DCF) and the centralized Point Coordination Function. DCF is the essential mechanism that uses the carrier sense multiple accesses with collision avoidance (CSMA/CA) protocol. Depending upon whether a channel is busy or idle, the CSMA/CA establishes a distributed MAC layer. When the channel is busy, the MAC will accept packets for an additional time interval after the medium becomes idle, called the DCF Inter-frame Space (DIFS). The MAC sublayer then chooses a random back-off counter (BC) to begin the back-off process if the channel remains empty through the DIFS deference period. The random BC is reduced for every time interval over which the medium remains empty. The BC is stopped if a station does not gain access to the medium in the first cycle and then waits for the DIFS to be empty again before the counter starts over. The station accesses the medium after the back-off window. Instead of choosing a randomized BC for the deferred stations, they continue to count down. This gives channels that have waited an advantage over new stations for a long time because the old channels no longer have a back-off window. Every channel is provided a contention window (CW) during which the random BC is selected. This randomized scheme has better resolving outcomes when the CW is larger since the large CW means that fewer channels will end up with the same BC. For each successful delivery of a frame, an acknowledgment (ACK) frame is communicated by the receiver to the transmitter. The short IFS (SIFS), which is shorter than the DIFS is followed by the ACK frame. This difference in the IFS lengths protects the ACK frame. If no ACK frame is transmitted, the CW size will double to CW_{max}. The CW value is set to CW_{min} after every successful communication. All of these parameters of the MAC sublayer, i.e., CW_{min}, CW_{max}, Slot Time, SIFS, and DIFS, are chosen in the PHY layer. The DIFS is defined as the SIFS + 2 × SlotTime. Fig. 2 gives a diagrammatic representation of a standard MAC sublayer.

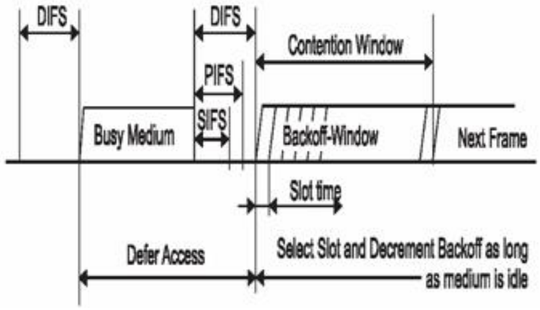

Fig. 2 IEEE 802.11a MAC structure

B. PHY Layer

The PHY layer used to implement OFDM for a 5 GHz frequency band and 20 MHz channel bandwidth is specified in the IEEE 802.11a standard. The possible raw data rates are 48, 36, 24, 18, 12, 9, and 6 Mbit/s. No center, “DC” or “Null,” zero subcarrier is used. The modulation format can vary from burst to burst, but the same modulation format is used within a burst. The achievable data subcarrier modulation structures included in IEEE 802.11a are BPSK, QPSK, 16 QAM, and 64 QAM. Pilot subcarriers are constantly modulated using BPSK with a known magnitude and phase [4]. Every subcarrier carries one modulated data symbol that is defined by the amplitude and phase of the radio pulse. This means that the phase and magnitude are different for every subcarrier and OFDM symbol in each transmitted burst.

This OFDM scheme uses a total of 52 subcarriers. Among 52 subcarriers 48 subcarriers are used for data and four subcarriers are pilots that helpful for coherent detection. Over a total signal bandwidth of 20 MHz, the spacing between the 64 subcarriers is 312.50 kHz [5].

III. IMPLEMENTING IEEE 802.11A IN GNU RADIO

GNU Radio is an open source used to implement SDRs using signal processing blocks. Particularly when related to other SDR frameworks it is multi hardware platformed i.e. used for various frontends. For example, Ettus Research company devices are well supported with GNU Radio community. It is not a fixed application-oriented environment. It can be used for any technology to provide solid base. GNU Radio previously aided as the ground for research in many areas like radio astronomy, satellite communication, multi-antenna systems, cognitive radio, localization and cooperative diversity. In GNU Radio Out-Of-Tree (OOT) modules, which are extended custom blocks, are used for implementing application-specific functionality [6], [7]. In this paper for implementing 802.11a we used one of the OOT module building blocks named as IEEE 802.11 was shown in Fig. 3.

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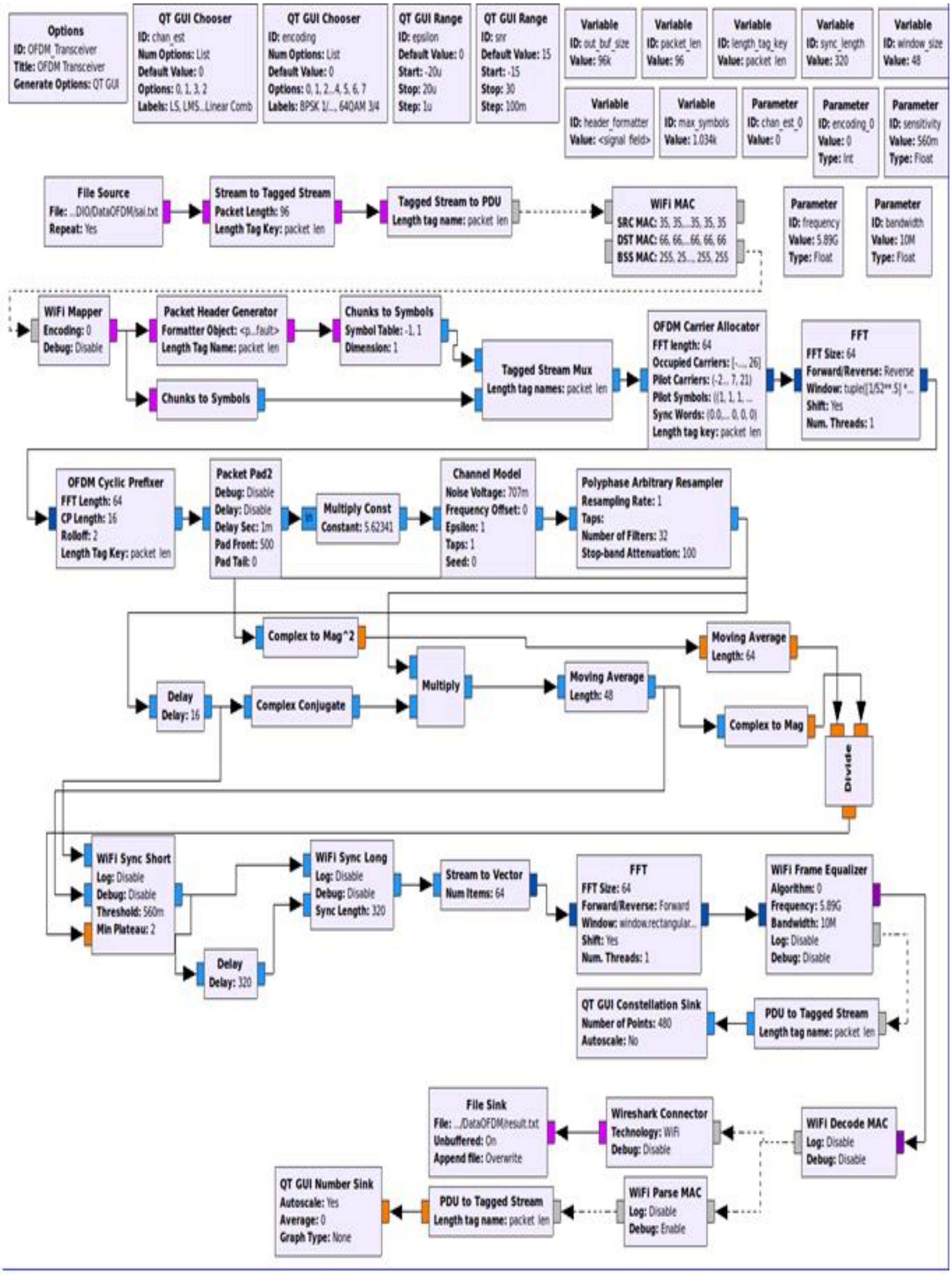

Fig. 3 OFDM Transceiver using GNU Radio

A. OFDM transmitter blocks in GNU Radio

Using GNU Radio IEEE 802.11 building blocks the transceiver was designed. A text file shown in Fig. 4(a) was taken as input to the transmitter block using “File source” block which was shown in Fig. 4(b).

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Telecommunication Systems https://doi.org/10.1007/s11235-017-0417-x An IEEE 802.22 transceiver framework and its performance analysis on software defined radio for TV white space Abhijeet Bishnu 1· Vimal Bhatia 1 © Springer Science+Business Media, LLC, part of Springer Nature 2017 Abstract With rapid increase in new applications and services, there is huge demand for internet bandwidth. Several researchers around the world have found that, majority of licensed bands (mostly terrestrial TV band) are either unused or underused. These underutilized bands allocated for TV transmission are known as TV white space (TVWS). For effective utilization of TVWS, the IEEE 802.22 is proposed. The IEEE 802.22 wireless regional area network (WRAN) is the latest standard for effective utilization of TV bands. This standard is based on orthogonal frequency division multiplexing with various modulation techniques to provide different data rates. In this paper, an implementation framework for physical layer of IEEE 802.22 WRAN standard for normal mode is demonstrated and analyzed. This transceiver is implemented using the National Instruments Laboratory Virtual Instrument Engineering Workbench programming software on the National Instruments universal software radio peripheral 2952R. We have also analyzed different blocks of IEEE 802.22 based on their execution time, and identify the critical blocks of IEEE 802.22 that should be optimized for real-time applications for commercial product development and field deployments. We have also highlighted the difference between theoretical and practical performance of the considered error control codes for IEEE 802.22 specified block size. Additionally, various covariance based spectrum sensing methods are also analyzed for real-world environment. Keywords TVWS · OFDM · IEEE 802.22 · SDR · Spectrum sensing 1 Introduction Rapid increase in various wireless technology applications and services pose a challenge on limited licensed spectrum. On the other hand, researchers have found that majority of the licensed spectrum bands in different parts of the world are underused in time, frequency and space [1]. In [2,3] the researchers through measurements have shown that most of the terrestrial TV band in very high frequency (VHF) and ultra high frequency (UHF) is unoccupied in rural and remote This work is supported by Ministry of Electronics and Information Technology (MeitY), Govt. of India under Visvesvaraya Ph.D. Scheme Grant Nos. PhD-MLA/4(65)/2014 and 14(3)/2014-CC & BT. B Abhijeet Bishnu phd1501102014@iiti.ac.in Vimal Bhatia vbhatia@iiti.ac.in 1 Signal and Software Group, Discipline of Electrical Engineering, Indian Institute of Technology Indore, Indore, India areas. These vacant/unused

Fig. 4(a) Input Data in Text File

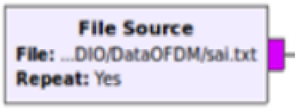

Fig. 4(b) File Source as Input

The input data was a set of bytes but to send data into a layer we must convert the data into packets. To know the boundary of a packet we must mention the boundary of the packet using a tag. This was done by "Stream to Tagged stream" block which was shown in Fig. 5(a). After that these packets were converted to Protocol Data Unit (PDU) form which contains user data and protocol control information and signifies part of data specified in the protocol of a given layer. PDU is used to communicate and exchange information from one layer to another layer of open-system interconnection (OSI), which can only be read by the equal layer on the receiving device and is then sent to next upper layer after stripping. This PDU conversion of the packets was done by "Tagged stream to PDU" was represented in Fig. 5(b).

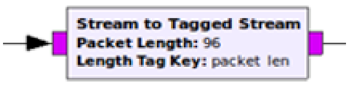

Fig. 5(a) Packet conversion Block

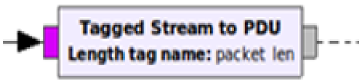

Fig. 5(b) PDU converting Block

To add MAC header which contains the frame type, source address (SRC), destination address (DST) and Base Station System (BSS) information we use "WiFi MAC" block shown in Fig. 6

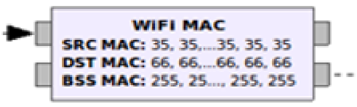

Fig. 6 MAC Layer converter

After MAC layer to process the data in PHY layer we must convert the MAC layer PDU information to bytes for this purpose we use "WiFi Mapper" block as shown in Fig.7.

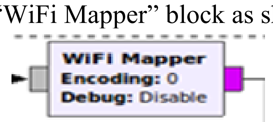

Fig. 7 MAC layer to PHY layer data converter

For every packet there will be a header which will carry the information of the packet. "Packet Header Generator" block represented in Fig. 8 generates the header for every packet for this purpose we must give the header formatter and the tag for every packet. This header is BPSK encoded at a ½ rate and modulated at 6 Mbps. This header was containing one OFDM symbol assigned to all 52 subcarriers.

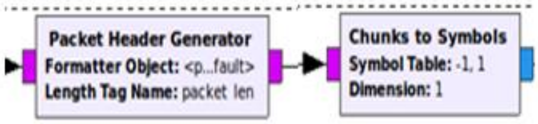

Fig. 8 Header Generator

The steps involved in OFDM PHY layer was followed in this GNU Radio implementation. In the process the first steps are scrambling, convolutional encoding and interleaving the payload data. After interleaving constellation mapping of the bits was done according to the given modulation type. In this paper the author was taken four various modulations "BPSK", "QPSK", "16 QAM" and "64 QAM" and considering the code rates for convolutional encoding as "1/2" and "3/4" for BPSK, QPSK and 16 QAM and "2/3" and "3/4" for 64QAM. This whole process was done in "chunks to symbols" block shown in Fig. 9.

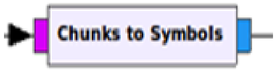

Fig. 9 Constellation Mapping

For prepending the designed header with the modulated payload data and again conforming the packet boundary with a tag was done by the "Tagged Stream Mux" block shown in Fig. 10. The modulated header data and payload data was given as input to this block.

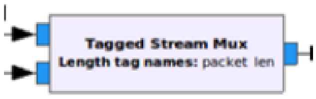

Fig. 10 Prepending Header before payload

For estimating the channel and synchronization purpose we must add pilots and preamble to the payload data and formation of OFDM symbol with null carriers was done in "OFDM Carrier Allocator" block shown in Fig. 11(a). In this block the pilot carriers, pilot symbols, data carriers, short preamble data and long preamble data was given as input information for this block this was shown in Fig. 11(b).

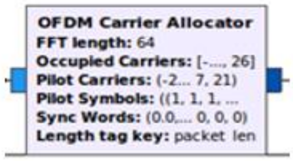

Fig. 11(a) OFDM Symbol Formation

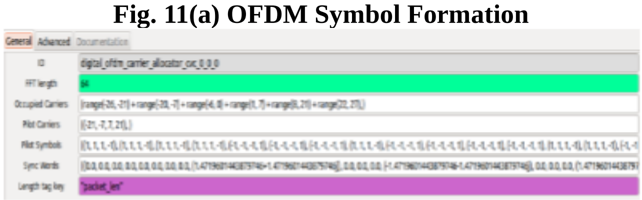

Fig. 11(b) Input information for "OFDM Carrier Allocator"

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Converting the frequency domain OFDM symbols into time domain signals was performed by IFFT. Because different orthogonal sinusoidal signals are used for time domain representation of OFDM. IFFT is used to convert frequency domain signals into time domain signal. This was done by the "FFT" block shown in Fig. 12.

Fig. 12 Converting from frequency domain to time domain.

To operate OFDM consistently Cyclic Prefix (CP) plays a major role. CP protects the OFDM from ISI by acting as a guard interval. It is created so that a copy of the end part of each OFDM symbol is headed to that same symbol. Here the length of the CP was 16 and this was done by "OFDM Cyclic Prefixer" which was shown in Fig. 13.

Fig. 13 Adding Cyclic Prefix

B. OFDM receiver blocks in GNU Radio

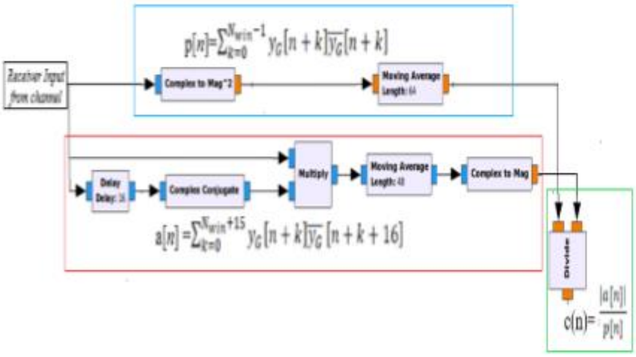

Fig. 14 Detection of Frame starting

OFDM receiver was having mainly two major parts to recover those are synchronization and channel estimation. This was done by using preamble data which was prepended for every frame [8]. For this purpose, we use equation 1, 2 and 3 for detecting the starting of a frame this was done by using blocks shown in Fig. 14.

The equation 3 is used for detecting the starting of the frame. Using two blocks "WiFi Sync Short" and "WiFi Sync Long" shown in Fig. 15 detection of Frame starting, Frequency offset correction and channel estimation was done. While we are moving from "WiFi Sync Short" to "Wifi Sync Long" we only transfer Long preamble data and short preamble data was detected and discarded in "WiFi Sync Short" block.

$$a[n] = \sum_{k=0}^{N_{win}+15} y_G[n+k]\overline{y_G}[n+k+16] \quad (1)$$

$$p[n] = \sum_{k=0}^{N_{win}-1} y_G[n+k]\overline{y_G}[n+k] \quad (2)$$

$$c(n) = \frac{|a[n]|}{p[n]} \quad (3)$$

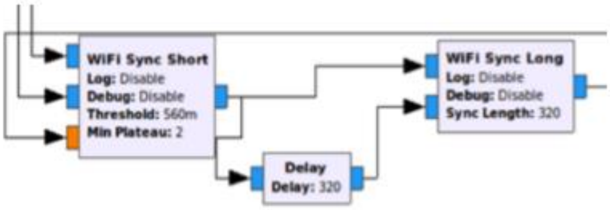

Fig. 15 Synchronization and Channel estimation

To recover the frequency domain signals FFT was used and de-map the data according to the given mapping at input. And it was done by the same block used in transmitter as shown in Fig. 12 but we have to select the option Forward for FFT.

By using "WiFi Frame Equalizer" block the channel estimation using pilots [9], [10], [11], [12]. constellation de-mapping and data transferring was done and then the data was changed to MAC layer PDU format using "WiFi Decode MAC" block shown in Fig. 16.

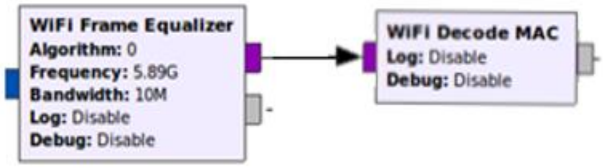

Fig. 16 Decoding Data

The decoded data was collected using "Wireshark connector" and displayed in wireshark which contains source address, destination address and which technology we are using etc. This output was shown in Fig. 17.

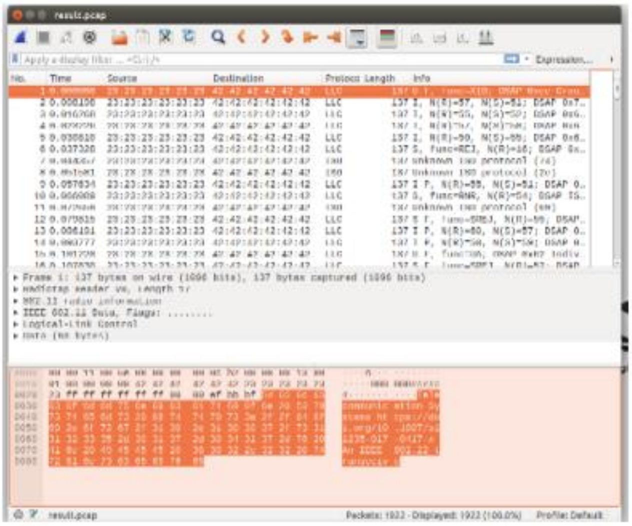

Fig. 17 Wireshark Connector Output.

IV. WIRELESS CHANNEL MODELS

The wireless channel environment condition was unpredictable and dynamic, this causes performance degradation in communication system. Because of this reason analysing a communication system is difficult. In communication system channel is one of the essential elements. In general, it acts as a distributing factor which can change the issued signal.

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A. FER Calculation for Additive White Gaussian Noise (AWGN) for IEEE 802.11a

In any wireless communication systems, the received signal consists of transmitted data, redundant signals created between sender and receiver and distortions enforced by transmission structure. The redundant signals are denoted as noise. The communication system performance was degraded by this noise and it was becoming a major limitation [13].

The performance of digital communication system is measured in the presence of thermal noiseusing the probability ofbit error rate. The tension of electrons causes thermal noise. It is a function of temperature which is present in all transmission media and electronic devices. Thermal noise is also denoted as white noise since it is uniformly distributed across the frequency spectrum. Due to vibration of atoms in the receiver electronics the thermal noise was generated. And this noise is called Additive White Gaussian Noise (AWGN). This gives the most effectively used equality in communication systems. The received signal (r) is equal to the addition of transmitted signal (t) and AWGN noise (w).

r=s+w

To study the performance of an IEEE 802.11 standard WLAN, NIST and YANS error rate models are used [14]. These models compute SNR based on the parameters used in simulation model such as noise figure, noise floor, path loss model etc. The FER is computed based on the applied modulation scheme, coding rate, and frame size [15]. Let us assume that convolution coding and hard decision Viterbi decoding are applied to the data symbols and transmitted over an AWGN channel model. In IEEE 802.11a the bit error probability is upper bound by following Chernoff Bound as per the NIST error rate model

$$P_b < \frac{1}{k}\sum_{d=d_{free}}^{\infty} B_d P(d)\,, P(d) = [(4p(1-p)]^{\frac{d}{2}} \quad (4)$$

Here, d_{free} is denoted as free distance of the convolution code, the total number of non-zero information bits are denoted as multiplication factor B_d, to select the transmitted code sequence, it denotes the probability of a weight $d$as output sequence and is denoted as $P(d)$,p is the simply the un-coded BER and the number of data bits per clock cycle is denoted as k. The FER can be expressed as

And the variance in Rayleigh distribution σ_R^2 (ac power in the envelope) can be derivated as

$$\sigma_r^2 = E[r^2] - E^2[r]$$

$$\sigma_r^2 = \int_0^{\alpha} r^2 P(r)dr - \frac{-\sigma^2\pi}{2} = 2\sigma^2 - \frac{\sigma^2\pi}{2} = 0.429\sigma^2 \quad (8)$$

For analysing the faded data under various fading conditions, the middle value of the envelope was used often.

Rician distribution was occurred at weaker multipath due to presence of the dominant signal.

The Rician distribution is a LOS dominant signal. The probability density function (pdf) for Rician distribution isexpressed as follows

$$P(r) = \left\{\frac{r}{\sigma^2} exp - \left(\frac{r^2+A^2}{2\sigma^2}\right) I_0\left(\frac{A_r}{\sigma^2}\right)\right\} \; for\; A \geq 0, r \geq 0 (9)$$

$$P(r) = \{0\}\; for\; r < 0$$

Here, A is denoted as the direct Line of Sight (LOS) signal peak amplitude and $I_0(x)$ is denoted as the improved Bessel function of thezero order first kind Bessel function. The fraction of the direct signal power and the variance of the multipath is denotes as K. K describes the Rician distribution.

$$FER = 1 - (1 - P_b)^L \quad (5)$$

Here, the aggregated MAC frame size is denoted as L. The standard size of L is basically 441 bytes. According to equation 5 the FER results for different modulations are given below

B. FER calculation for fading channels

Received signal in the communication system is affected by the fading due to diffraction, shadowing, reflection, scattering and multipath propagation caused by the barriers such as trees, houses, buildings and mountains. Because of this multipath transmission the communicated signals reach in various phase angles, time interval and amplitude. Fading is an effect which causes the variations in the amplitude of the received signal because of changes in multipath like time variant and frequency selective. Depending on the strength of scattering components during transmission, this fading effect was divided as Rician probability distribution and Rayleigh probability distribution.

Rayleigh fading is nothing but the presence of several indirect paths between the source and the destination. And this is called Non-Line of Site (N-LOS). This can be used in tough environments such as centre of urban areas. For representing a statistically time varying nature and flat fading nature of environment in the wireless communication systems, the Rayleigh distribution is usually used. For a scattered envelope r(t)of Rayleigh fading, the probability density function (pdf) is expressed as follows

$$P(r) = \left\{\frac{r}{\sigma^2} exp\left(\frac{-r^2}{2\sigma^2}\right)\right\} \; for\; 0 \leq r \leq \propto \quad (6)$$

$$P(r) = \{0\}\; for\; r < 0$$

Received voltage signals rms value was represented as σ andat the envelope detector, $\sigma^2$is the average power time.Thereceived signal's probability is up to a defined given value R is denoted as follows

$$P(R) = P_r(r \leq R) = \int_0^R P(r)dr \approx 1 - \exp\left(\frac{R^2}{2\sigma^2}\right) \quad (7)$$

The following expression gives $r_{mean}$for such distribution

$$r_{mean} = E[r] = \int_0^{\alpha} r\, P(r)dr = \sigma\sqrt{\frac{\pi}{2}}$$

$$K = 10log\frac{A^2}{2\sigma^2}dB$$

The Rician distribution will be converted into Rayleigh distribution when there is absence of direct LOS. This type channel fading effects in wireless communication system was solved by using equalizers, appropriate diversity schemes or error control codes.

According to the Jake spectrum let us consider the flat fading Rayleighwireless channel conditions. The level of received signal powerin fading or inter-fading states is estimated as a threshold value. If the complete frame is in inter-fading state then there will be a successful transmission of frame. The receiver gets an errored frame ifeven some part of the frame is in fading period. The fading margin ρ in the fading channel is measured as

$\rho = R_{req}/R_{rms}$

Here the required received power level is denoted as R_{req} and the mean received power is denoted as R_{rms}.Generally, the exponential distribution for ρ<-10dB is considered as fading period and inter-fading period. From the above conventions, let be the frame period, then the frame error rate is

$$FER = 1 - \frac{T_i}{T_i+T_f} P(t_i > T_{pi}) \qquad (10)$$

where, $t_i$represents inter-fading period and $t_f$represents fading period. The random variable t_i's average value is represented as T_i and the random variablet_f'saverage value is represented as T_f. $P(t_i>T_{pi})$ is the probability that inter-fading period lasts longer than T_{pi}. Since exponential distribution is assumed for t_i, $P(t_i > T_{pi}) = exp\left(\frac{-T_{pi}}{T_i}\right)$. The average fading duration for Rayleigh fading channel is given by

$T_i = \frac{exp(\rho)-1}{f_d\sqrt{2\pi\rho}}$.

$T_i + T_f$ is $\frac{1}{N_f}$, where the level crossing rate is denoted as N_f, which is given by $f_d\sqrt{2\pi\rho}exp(-\rho)$. The maximum Doppler frequency is denoted as f_d and estimated as $, v - \lambda . v$ is the speed of the mobile and λ is the wavelength? Frame error rate can be stated by

$$FER = 1 - exp\left(-\rho - f_d\sqrt{2\pi\rho}T_{pi}\right) \qquad (11)$$

V. EXPERIMENT RESULTS AND DISCUSSION

As described in Section 4 in this paper we considered three different channel conditions for simulating IEEE 802.11a transceiver and analysed the channel conditions depending upon the results displayed.

A. Numerical Results of FER over the AWGN Channel

For calculating the FER for AWGN channel equation 18 was considered. According to the given modulations and SNR given the FER results were plotted. The constellation plots, signal spectrums and FER calculations for different modulations and different coding rates was shown in Fig. 18, Fig. 19, Fig. 20, Fig. 21, Fig. 22 and Fig. 23(a) and (b) respectively. By observing the plots, we candecide that at best signal rate we can receive a best data with less error rate even in AWGN channel.

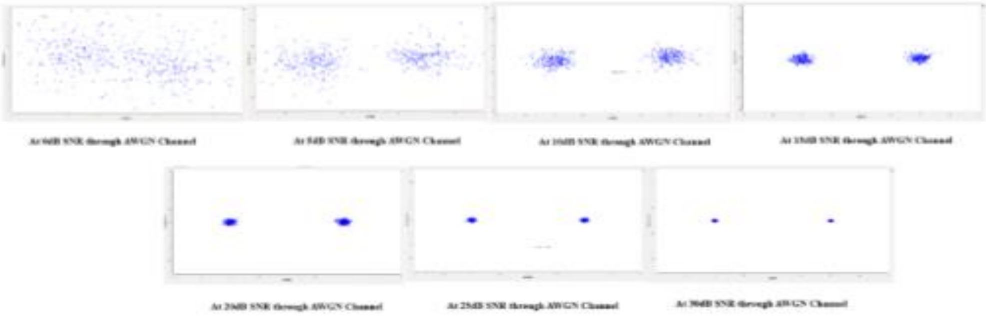

Fig. 18 Constellation plots for BPSK at SNR's from 0dB to 30dB

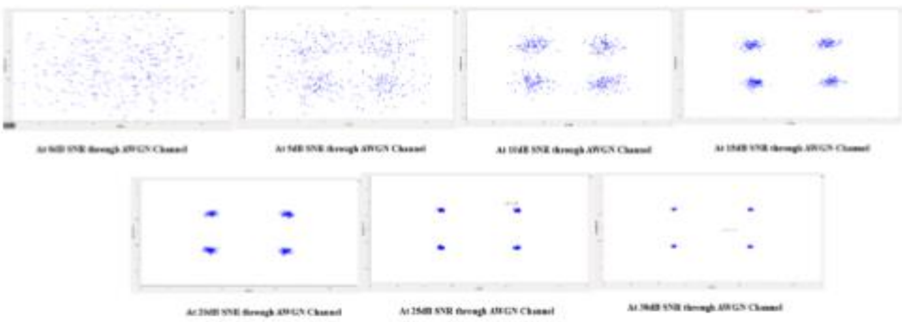

Fig. 19 Constellation plots for QPSK at SNR's from 0dB to 30dB through AWGN channel

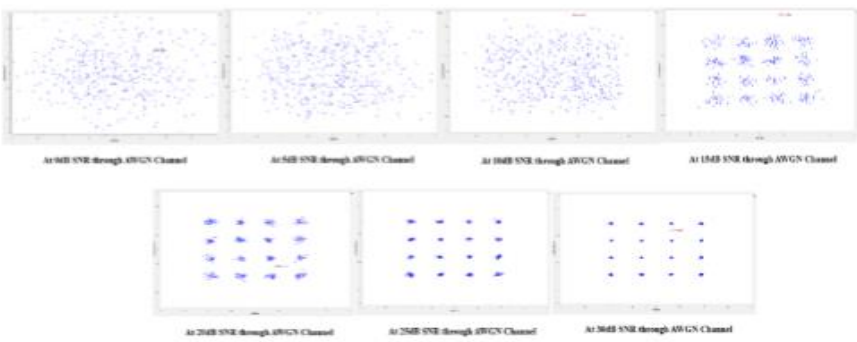

Fig. 20 Constellation plots for 16 QAM at SNR's from 0dB to 30dB through AWGN channel

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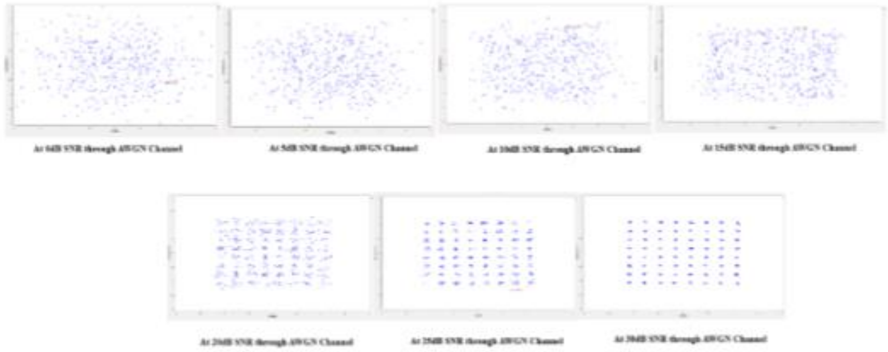

Fig. 21 Constellation plots for 64 QAM at SNR's from 0dB to 30dB through AWGN channel

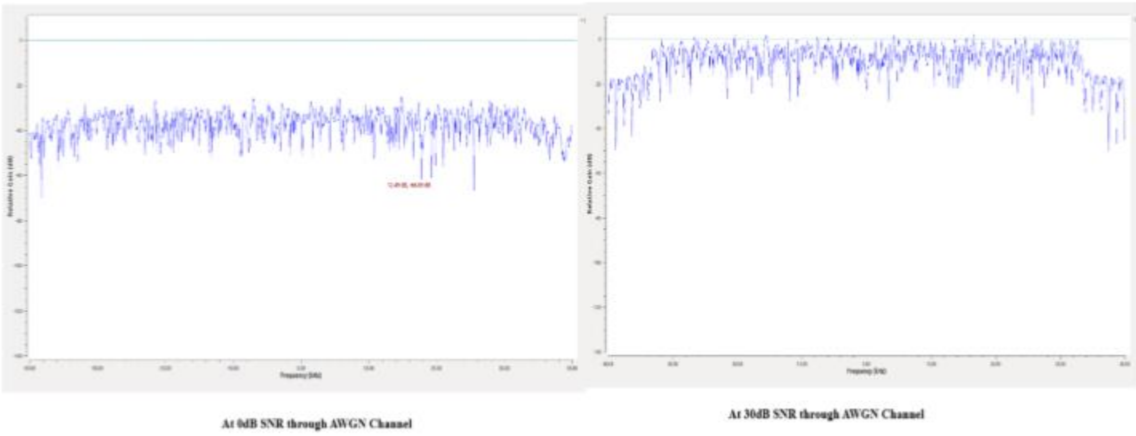

Fig. 22 OFDM received signal spectrum at 0dB and 30dB through AWGN channel

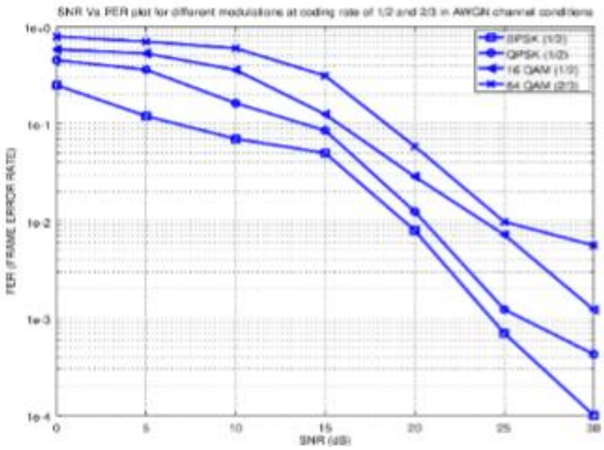

Fig. 23(a) SNR Vs FER for BPSK (1/2), QPSK (1/2), 16 QAM (1/2), 64 QAM (2/3) through AWGN channel

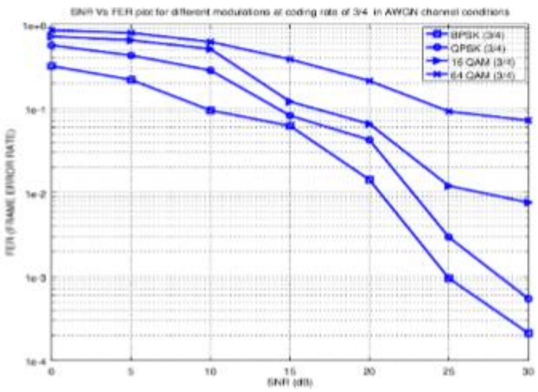

Fig. 23(b) SNR Vs FER for BPSK (3/4), QPSK (3/4), 16 QAM (3/4), 64 QAM (3/4) through AWGN channel

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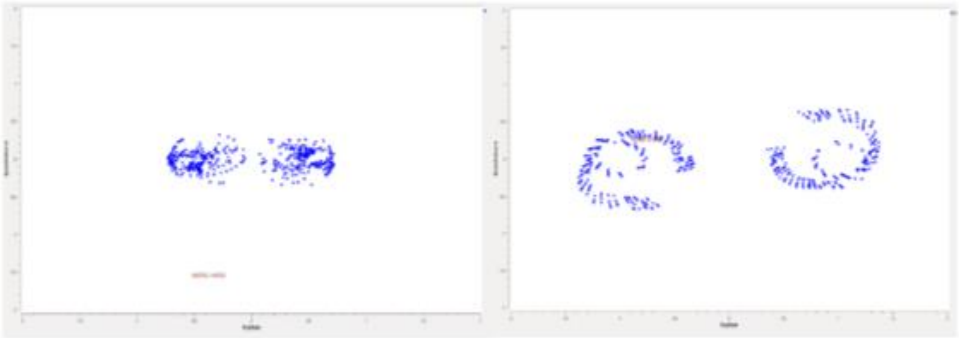
B. Statistical Results of FER over the Rayleigh Channel

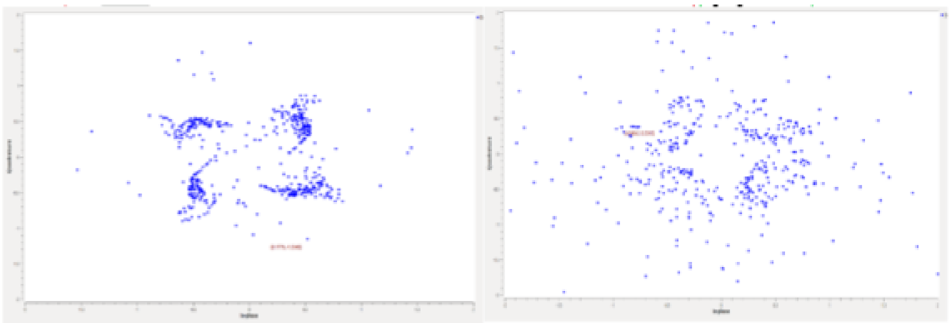
For FER calculation in Rayleigh and Rician channel we use equation 11. In equation 11f_d is the maximum Doppler frequency, defined as $f_d = \frac{v}{\lambda} = \frac{f_c v}{c}$. Here, v= velocity of the mobile (ms^{-1}), fc= carrier frequency 5.89 GHz and c=3$x10^8 ms^{-1}$. Normalized Doppler frequency can be defined as fD=$fmTs$, here $Ts$is the symbol period. As a result, FER in wireless channel depends on Doppler frequency shift, fading margin and frame duration. Again, to estimate the performance of the receiver, FER is calculated for different values of SNR (dB) where the selected data rate is 24 Mbps, the chosen modulation scheme and transmission medium is the frequency selective fading channel. The channel is simulated by introducing a tapped delay line FIR filter with an exponentially declining average power delay profile (PDP). The number of taps given in FIR filter is 8 and tap characteristics is chosen as Rayleigh distributed (NLOS) and Rician distributed (LOS) exclusively. A normalized Doppler shift ($fDTs$) is added to get the relative characteristics while the receiver is not stationary.

In Fig. 24, Fig. 25, Fig. 26, Fig. 27, Fig. 28 and Fig. 29(a) and Fig. 29(b) shows different results regarding constellation plots, signal strength and FER vs SNR respectively. By observing the results, we can analyse that where we are having less doppler shift there we can receive the signal with less error rate. And in this paper, we are using Least Square (LS) channel estimation technique for recovering the data.



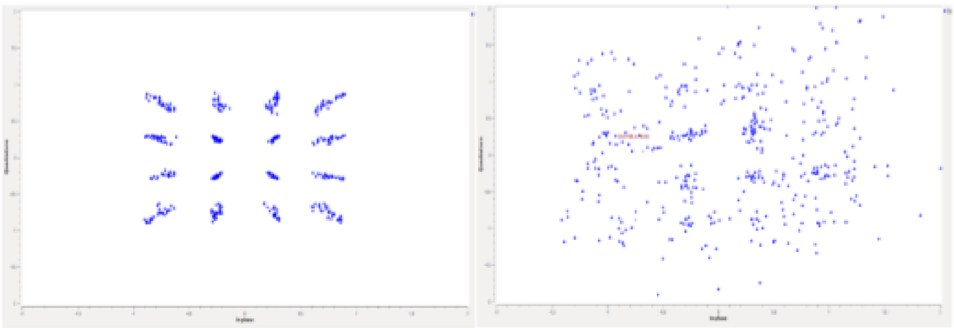
BPSK at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.0001$ BPSK at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.005$

Fig. 24 Constellation plots for BPSK at SNR at 20dB for f_dT_s= 0.0001 and 0.005



QPSK at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.0001$ QPSK at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.005$

Fig. 25 Constellation plots for QPSK at SNR at 20dB for f_dT_s= 0.0001 and 0.005



16QAM at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.0001$ 16QAM at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.005$

Fig. 26 Constellation plots for 16 QAM at SNR at 20dB for f_dT_s= 0.0001 and 0.005

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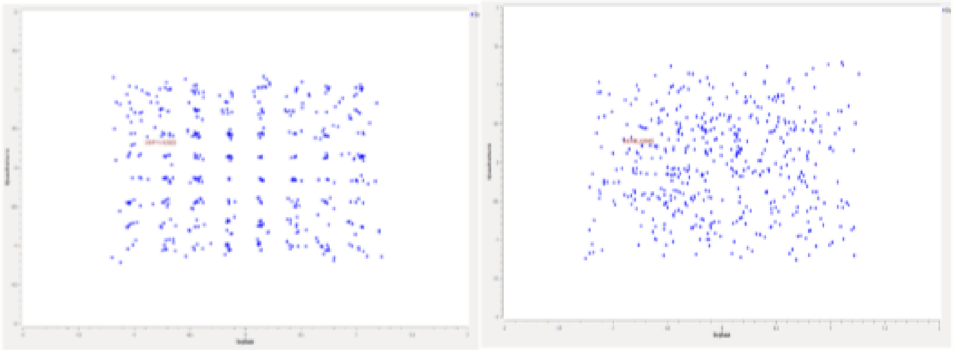
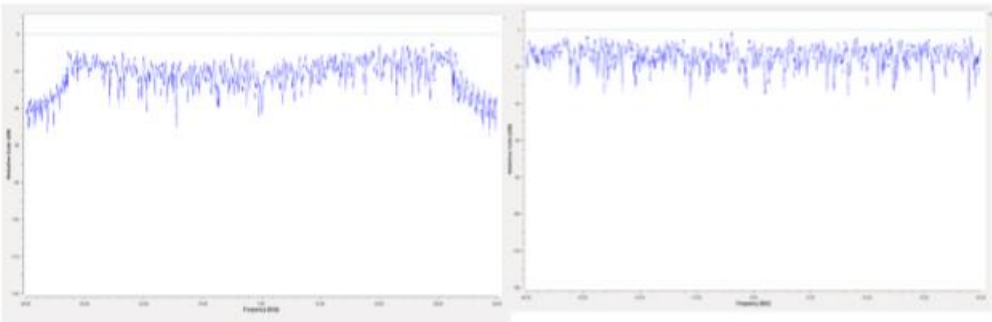


64QAM at20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.0001$ 64QAM at 20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.005$

Fig. 27 Constellation plots for 64 QAM at SNR at 20dB for f_dT_s= 0.0001 and 0.005



At20dB SNR through Rayleigh Fading Channel and $f_dT_s = 0.0001$ At20dBSNR through Rayleigh Fading Channel and $f_dT_s = 0.005$

Fig. 28 OFDM Signal Strength at SNR at 20dB for f_dT_s= 0.0001 and 0.005

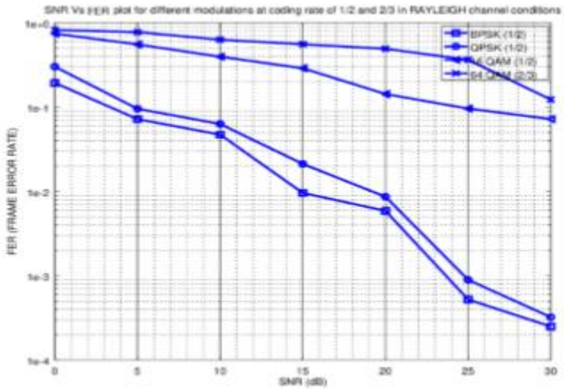


Fig. 29(a) SNR Vs FER for BPSK (1/2), QPSK (1/2), 16 QAM (1/2), 64 QAM (2/3) through Rayleigh channel for f_dT_s= 0.0001

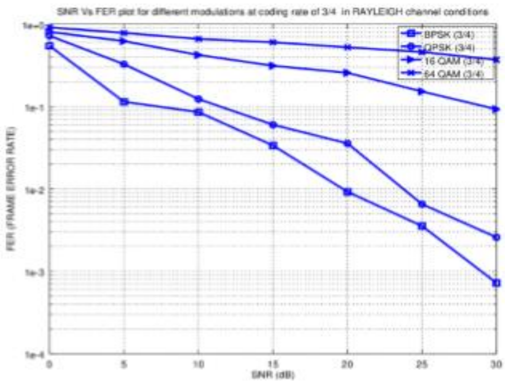


Fig. 29(b) SNR Vs FER for BPSK (3/4), QPSK (3/4), 16 QAM (3/4), 64 QAM (3/4) through Rayleigh channel for f_dT_s= 0.0001

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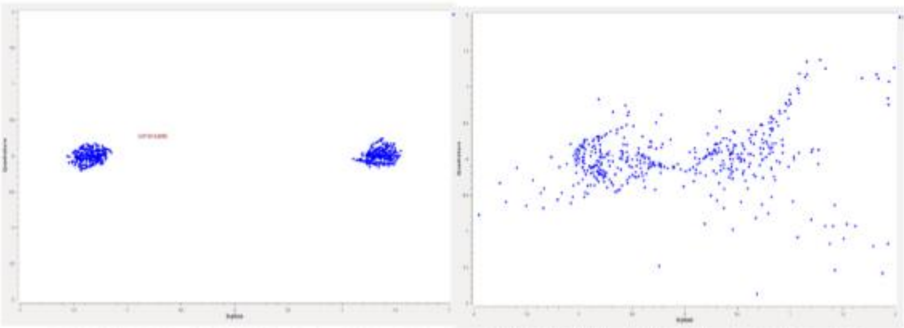
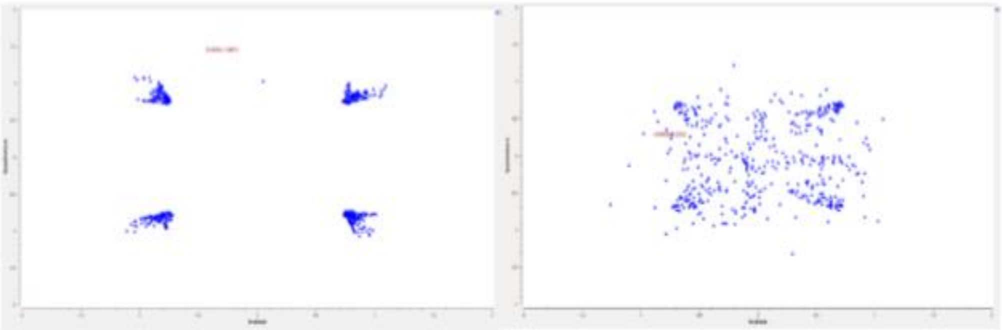
C. Statistical Results of FER over the Rayleigh Channel

In Fig. 30, Fig. 31, Fig. 32, Fig. 33, Fig. 34 and Fig. 35(a) and Fig. 35(b) shows different results regarding constellation plots, signal strength and FER vs SNR of Rician channel conditions respectively. By observing the results, we can analyse that where we are having less doppler shift there we can receive the signal with less error rate. And in this paper, we are using Least Square (LS) channel estimation technique for recovering the data.



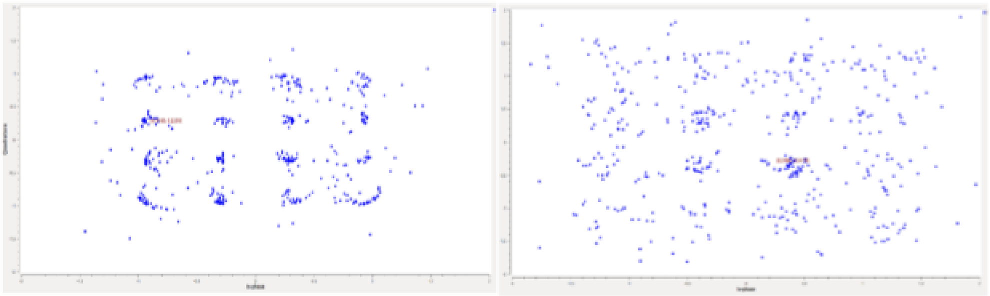
BPSK at20dB SNR through Rician fading channel and $f_dT_s = 0.0001$ BPSK at20dB SNR through Rician fading channel and $f_dT_s = 0.005$

Fig. 30 Constellation plots for BPSK at SNR at 20dB for f_dT_s= 0.0001 and 0.005



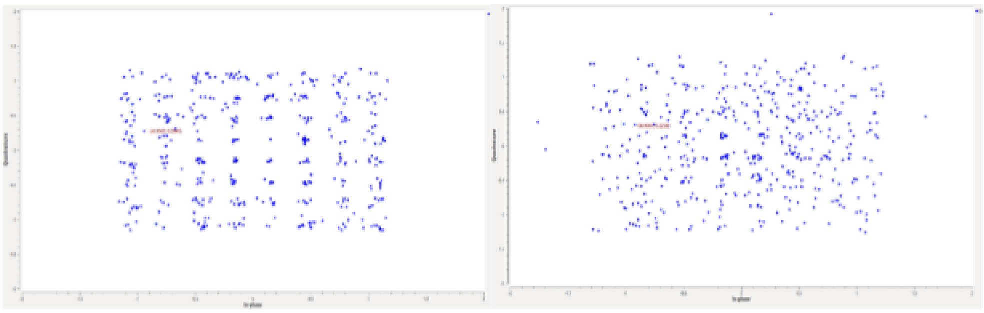
QPSK at20dB SNR through Rician fading channel and $f_dT_s = 0.0001$ QPSK at20dB SNR through Rician fading channel and $f_dT_s = 0.005$

Fig. 31 Constellation plots for QPSK at SNR at 20dB for f_dT_s= 0.0001 and 0.005



16QAM at20dB SNR through Rician fading channel and $f_dT_s = 0.0001$ 16QAM at20dB SNR through Rician fading channel and $f_dT_s = 0.005$

Fig. 32 Constellation plots for 16 QAM at SNR at 20dB for f_dT_s= 0.0001 and 0.005



64QAM at 20dB SNR through Rician fading channel and $f_dT_s = 0.0001$ 64QAM at 20dB SNR through Rician fading channel and $f_dT_s = 0.005$

Fig. 33 Constellation plots for 64 QAM at SNR at 20dB for f_dT_s= 0.0001 and 0.005

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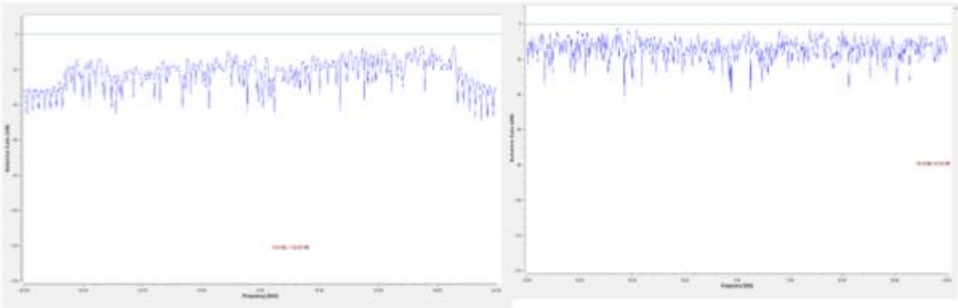

At 20dB SNR through Rician fading channel and f_dT_s = 0.0001   At 20dB SNR through Rician fading channel and f_dT_s = 0.005

Fig. 34 OFDM Signal Strength at SNR at 20dB for f_dT_s= 0.0001 and 0.005

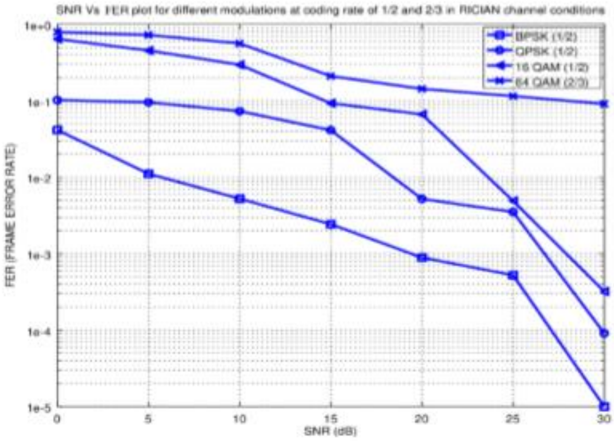

Fig. 35(a) SNR Vs FER for BPSK (1/2), QPSK (1/2), 16 QAM (1/2), 64 QAM (2/3) through Rician channel for f_dT_s= 0.0001

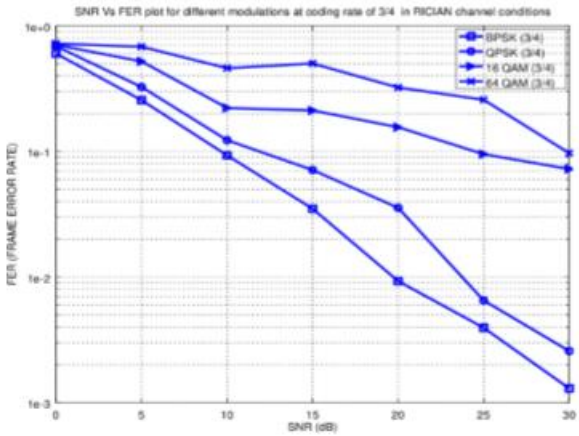

Fig. 35(b) SNR Vs FER for BPSK (3/4), QPSK (3/4), 16 QAM (3/4), 64 QAM (3/4) through Rician channel for f_dT_s= 0.0001

VI. CONCLUSION

In this paper IEEE 802.11a standard protocol was analysed and tested in different channel conditions using an open source GNU Radio. This paper explored the FER performance of MAC layer in the IEEE 802.11a under the typical channel by transferring a fixed data. The wireless channels assumed to be AWGN, Rician fading channel and Rayleigh fading channel. The data was displayed using Wireshark connector. By implementing this protocol on SDR there is a chance to move to real time environment. In future this block was implemented in real time and the results are compared with the simulations. The advantage of developing this protocol on SDR was we can change the techniques of synchronization and channel estimation according to our requirement without any disturbing the hardware environment.

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