Int. Conf. on Signal, Image Processing Communication & Automation, ICSIPCA

Comparative Performance Analysis of M-FSK and M-PSK Transceiver for Cognitive Radio Applications

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***Abstract*— With the rapid growth of wireless communication, Cognitive radio (CR) is a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and which are left open, and instantly move into vacant channels while avoiding occupied ones. This most effective use of available radio-frequency (RF) spectrum while minimizing interference to other users. The main objective of this paper is to comparative performance analysis M-Frequency Shift Keying (FSK) and M-Phase Shift Keying (PSK) transceiver for CR applications using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) This paper describes the fundamental concept for the design and implementation of a CR-based transceiver simulation model under FSK/PSK, Schemes, and to measure the Bit Error Rate (BER) in the presence of Additive White Gaussian Noise (AWGN) channel & analyses the performance of different types of codes. In this paper we have compare that how FSK gives very good BER providing high data rate and used to control the power for CR system than PSK. The BER curves for MFSK and MPSK obtained after simulation are compared with theoretical curves.**

***Index Terms*— Cognitive Radio, Digital communication, Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Additive White Gaussian Noise (AWGN), Bit error Rate (BER), Signal-to-Noise Ratio (SNR), LabVIEW graphical programming.**

I. INTRODUCTION

From many years modulation techniques have been designed and extensively used for various applications but the modern communication system requires data transmission at a higher rate, larger bandwidth in order to have the multimedia transmission.

This paper discusses a Cognitive Radio (CR) is an advanced version of software-defined radio (SDR) system using LabVIEW for FSK/PSK Transceiver. Cognitive radio (CR) provides a new paradigm (an alternative) to systems such as the third generation (3G) and the fourth generation (4G). There are two frequency bands where the cognitive radios might operate in the near future i.e. 54-862 MHz (VHF and UHF TV bands) and 3-10 GHz (Ultra-wideband (UWB) radios) [2].

"Fig. 1" shows the CR system architecture. The system is hybrid and consists of two networks; a primary radio network and a cognitive "adaptive" radio network. The two networks are not physically connected however they meant to coexist [3]. A Cognitive radio consists of a digital programmable communication system by updating software, functional changes can be made. Similar to other digital communication

Grenze ID: 02.ICSIPCA.2017.1.20

systems, the transmitter of a CR system converts digital signals to analog waveforms and then these waveforms are then transmitted to the receiver. On a reconfigurable baseband processor, the received waveforms are down converted, sampled, and demodulated using the software.

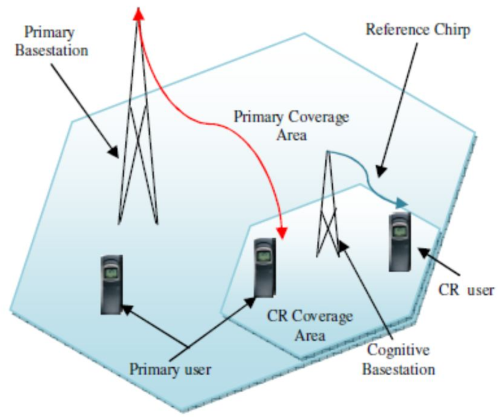

Figure 1. CR System Architecture

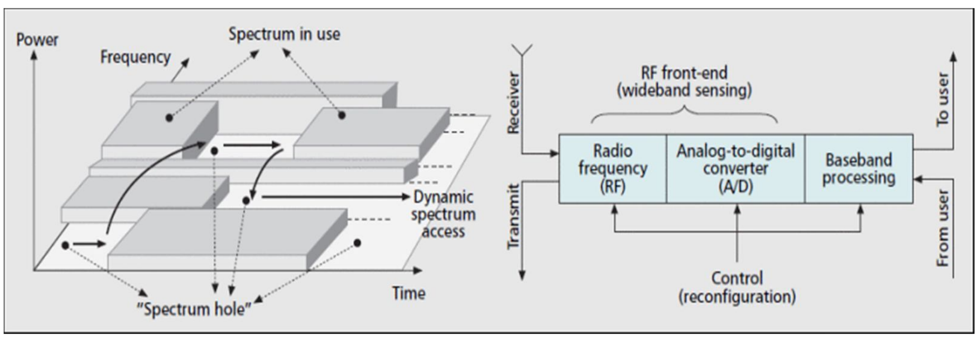

Figure 2. Overview of cognitive radio: a) The spectrum hole concept; b) Cognitive radio transceiver architecture.

As shown in "Fig. 2a", CR enables the usage of temporally unused spectrum, referred to as spectrum hole or white space. The main components of a CR transceiver are the Radio front-end (wide band sensing) and the baseband processing unit that were originally proposed for software-defined Radio (SDR), as shown in "Fig. 2b" [18]. In the RF front-end the received signal is amplified, mixed with amplified signal and analog-to-digital (A/D) converted. The signal is modulated/demodulated in the baseband processing unit. Each component can be reconfigured through a control bus to adapt to the time-varying RF environment. The characteristic of the CR transceiver is the wideband RF front-end that is capable of simultaneous sensing over a wide range of frequency. This functionality is related to the RF hardware technologies, such as wideband antenna, power amplifier, and adaptive filter. RF hardware for the CR should be capable of being tuned to any part of a large spectrum range. However, because the CR transceiver receives signals from various transmitters operating at different power levels, band-widths, and locations; the RF front-end should have the capability to detect a weak signal in a large dynamic range. It is a major challenge in CR transceiver design [18].

One of the main advantages of using digital modulation technique is that the use of digital signals reduces hardware, noise and interference problems as compared to the analog signal where a large number of waveforms will be required and resulting in a larger bandwidth for the symbol to be transmitted.

In this paper, Frequency Shift Keying (FSK) is chosen to be the modulation scheme of the designed Cognitive radio system noting that this modulation is widely used for data transmission and applications over band pass channels such as Cordless and paging systems, Telephone-line modems, Caller ID, Microcomputers, Audio cassettes, Radio control etc. Due to its easy implementation and widespread usage in legacy communications equipment, FSK modulation techniques to be very common technology for transmission and reception in current and future wireless communication, especially in the VHF and UHF frequency bands giving very good BER with high data rates. Transferring from analog formats to digital formats data communications is growing importance, and along with it the various forms of modulation which are used to carry data [1].

In this paper, the software simulation of the FSK/PSK Transceiver system is accomplished using LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) [4] as a time-efficient and cost-effective solution. LabVIEW is a graphical programming language developed by National Instruments which allows high-level or system-level design via its flow-chart intuitive block-based programming as compared to the commonly used text-based programming languages [5]. A design is achieved by integrating different blocks, components or subsystems, called Virtual Instruments (VIs), within a graphical framework using LabVIEW.

II. Block diagram of the digital communication system

Detailed block diagram of the digital communication system based on M-ary (MPSK, MQAM, MFSK) modulation scheme as shown in “Fig 5”. The first three modules (information source (message), pulse shape filter, and FSK modulator) make up the transmitter part and the other modules make up the receiver part [6].

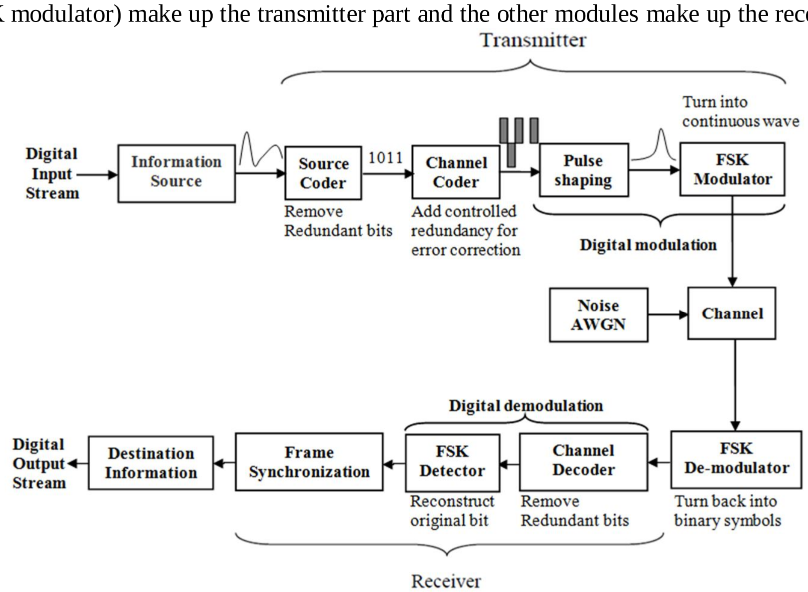

Figure 5. Block diagram of digital communication system based on M-ary (MPSK, MQAM, MFSK) modulation scheme.

A brief description of each block as follows.

A. Digital Input Stream

This is a sequence of binary bit streams (ones and zeros) or information often termed as baseband (low-pass) signal to be modulated.

B. Information/Message source

The first component of the FSK Transceiver is the message source. The Information or message to be transmitted comes from the information source. Here, Pseudo Noise (PN) sequences are used for this purpose.

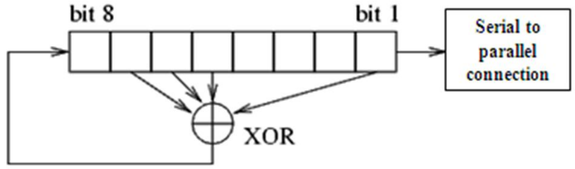

Figure 6. PN generation with shift register and XOR gate.

In order to create the message sequences for both the in-phase and quadrature phase components two PN sequence generators are used. In the constellation of 4-FSK, the reference signals are located at each quadrant. A PN generator produces a sequence of bits that appears random. As shown in “Fig. 6”, the PN generator is simply a shift-register and XOR gate. The shift-register bits 1, 5, 6, and 7 are XOR^{ed} together and the result is shifted into the highest bit of the register. The lowest bit, which is shifted out, is the output of the PN generator. The PN generator is a useful source of random data bits for system testing. The PN sequence will repeat with period $N= 2^m-1$, where m is the width in bits of the shift register. The sequence generated via Eq. has a period of 31bits ($=2^5-1$).

C. Source Encoder

To improve efficiency by reducing redundant bits, compressing the digital sequence into a more competent symbol for transmission using source encoder.

D. Channel Encoder (Line)

To improve reliability by adding redundant bits to the compressed information in order to control the errors offered by channel impairments using channel encoder. There are different methods of line coding which includes unipolar encoding, polar encoding, bipolar encoding, Manchester encoding.

E. Pulse shape filter

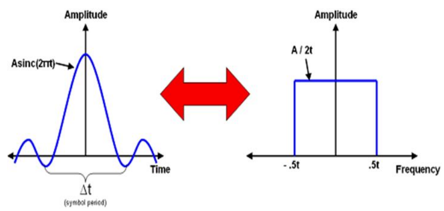

Figure 7. Pulse shape filter

In communications systems, two important requirements of a wireless communications channel demand the use of a pulse shaping filter [16] as shown in “Fig. 7”.
These requirements are:

- Generating band limited channels, and
- Reducing Inter Symbol Interference (ISI) arising from multi-path signal reflections and also reduces adjacent channel interference.

By a pulse shaping filter which is applied to each symbol both requirements can be accomplished.

- Nyquist techniques reduce the bandwidth requirement and eliminate inter symbol interference.
- Non-Nyquist techniques reduce the bandwidth requirement but do not eliminate inter symbol interference.

F. FSK modulator

The FSK modulator converts the input bit stream into an electrical waveform suitable for transmission over the communication channel. Modulator can be effectively used to minimize the effects of channel noise, also to match the frequency spectrum of transmitted signal with channel characteristics, and to provide the capability to multiplex many signals. To build a complex envelope the output of the raised cosine filter is used. By shifting the frequency of a continuous carrier in a binary manner to one or the other of two discrete frequencies the data is transmitted. One frequency is designated as the “space” (0) frequency and the other as the “mark” (1) frequency.

G. Channel

The electrical connection between the source and destination using Channel. The different channels which are used broadly are Coaxial cable, Optical fibre, pair of wires, Satellite channel, radio channel or combination of any of these.

H. Noise (Additive White Gaussian Noise (AWGN))

Noise is random, undesirable electrical energy that can interfere with the transmitted message in a communications system. The most common type of noise added over the channel is the Additive White

Gaussian Noise (AWGN) in communication systems. The received signal is equal to the transmitted signal plus the noise is additive. It has a constant power spectral density is white. Its probability density function can be accurately modeled to behave like a Gaussian distribution is Gaussian. It is noise because it distorts the received signal. The more is the deviation of the received symbols as the variance of the noise is higher with respect to the constellation set and, thus in AWGN the probability to demodulate a wrong symbol is higher and makes errors.

I. FSK demodulator

FSK demodulation is the process of recovering the original message from the information bearing waveform produced by the modulation is accomplished by the demodulator. The output of the FSK demodulator is bit stream.

J. Channel decoder (Line)

The information bearing bits from the coded binary stream recovers from Channel decoder. The channel decoder performs error detection and possible correction.

K. Source decoder

Conversion of the binary output of the channel decoder into a symbol sequence is called source decoder. The decoder for a system using fixed – length code word is very simple, but the decoder for a system using variable – length code words will be quite complex.

L. Frame Synchronization

For properly grouping transmitted bits into an alphabet, Frame synchronization is required. In order to achieve this synchronization, a measure, consisting of cross correlation, is computed between the known marker bits and received samples.

M. Digital Output Stream

Recovers the message from the electric signal.

III. MFSK / MPSK TRANSCEIVER PARAMETERS

A. Transmitter filters

Transmitter filter defines the type of band-limiting filter employed at transmitter for pulse shaping the symbols output by the modulator. There are many different varieties of filtering as shown in figure 7. The most common are

- Raised cosine (Nyquist)
- Square-root raised cosine
- Gaussian filters

Raised cosine filter: One of the most common pulse-shaping filters in communications systems is called raised cosine filter is. It is used to minimize inter symbol interference (ISI).
Root Raised Cosine Filter: Low frequency produces a frequency response with unity gain and complete at higher frequencies is called root raised cosine filter.
Gaussian filter: The Gaussian pulse-shaping filter reduces the levels of side-lobes of the FSK & GMSK spectrum.

B. FSK System Parameters (M)

Symbol map: Specifies an ordered array that maps each Boolean symbol to its desired deviation frequency. The number of FSK levels in the array must be 2^N, where N is the number of bits per symbol.
Symbol phase continuity: Specifies whether the phase transitions between symbols are continuous.
Continuous (0): Specifies continuous phase transitions between symbols. This value is the default.
Discontinuous (1): Specifies discontinuous phase transitions between symbols, that is, discontinuous phase FSK (DPFSK).
FSK deviation: Specifies the maximum FSK frequency deviation. At base band frequencies, deviations for individual symbols are evenly spaced in the interval $[-f_d, f_d]$, where f_d represents the frequency deviation. The default value is 15,000.

M-FSK: Specifies the *M*-ary number, which is the number of distinct frequency deviations to use as symbols. This value must be a positive power of 2.As the number of levels increases the amount of information transmitted increases – but the probability of receiving an error also increases.
Sample per symbol: Samples per symbol are the ratio of the sampling rate employed by system to the transmitter symbol rate.
Symbol rate or Baud rate (R_s), Hz: The signal bandwidth for the communications channel depends on the symbol rate or also known as band rate. Symbol rate the number of transmitted symbols per second.
R_s=1/T,T = time of one signaling element or Symbol period, The Symbol rate (R_s) is measured in symbol/second.
Symbol rate =bit rate/the number of bits transmitted with each symbol

IV. BIT ERROR RATE (BER) & SIGNAL-TO-NOISE RATIO (SNR)

A. Bit Error Rate (BER) for MFSK and MPSK

In digital communication system, the number of bit errors is the number of received bits of a data stream over communication channels that have been altered due to noise, distortion, interference or bit synchronization errors in the system. The bit error rate or bit error ratio (BER) is the ratio of the number of bit errors to the total number of transferred bits during a considered time interval. The BER measurement is simple send a data stream through the system and compares the output to the input its execution is not trivial. BER is a unit less performance measure. It is expressed as a percentage (%). Over an infinitely long period of time, can assume that a data transmission is a random process. A pseudorandom data sequence is used for both MPSK & MFSK. The “Pseudo” random cannot create a truly random signal using deterministic (mathematical) methods. The BER parameter represents the current operating of a specific modulation type for BER. This value depends on several channel characteristics, including the noise level and transmits power and noise level. Better accuracy of the transmitted digital signal is measured by BER (see “Fig. 8”).
In this paper we discuss the BER Vs the SNR achieved for different M-PSK in a noisy channel for both the Convolution and Turbo coding and BCH codes or Bose–Chaudhuri–Hocquenghem codes for different M-FSK in a noisy channel. A pseudorandom data sequence (15) is used for the analysis in this design of M-PSK. But a pseudorandom data sequence (9) is used for the analysis in this design of M-FSK.
Simply put, BER is:

$$BER = \frac{The\ no. of\ error\ bits}{The\ total\ no. of\ bits}$$

MFSK: Increasing *M* decreases BER and decreases bandwidth Efficiency
MPSK: Increasing *M* increases BER and increases bandwidth efficiency

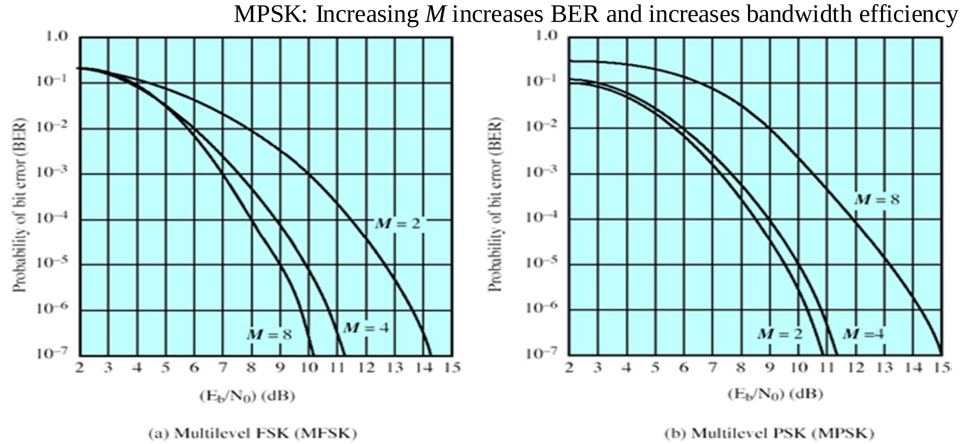

Figure 8. Theoretical BER vs. E_b / N_o for Multilevel FSK and Multilevel PSK

B. Signal-to-Noise Ratio (SNR)

It is used to measure the quality of a system. The ratio of the modulated energy per information bit to the one-sided noise spectral density; namely,

$$SNR = \frac{Modulated\ energy\ per\ bit}{Noise\ spectral\ density} = \frac{E_b}{N_0} dB$$

To find the theoretical bit rate limit, SNR is defined as the ratio of a signal power to noise power and it is normally expressed in decibel (dB). The mathematical expression of SNR is

$$SNR = 10 log_{10} \frac{Average\ signal\ power}{Noise\ signal\ power} dB$$

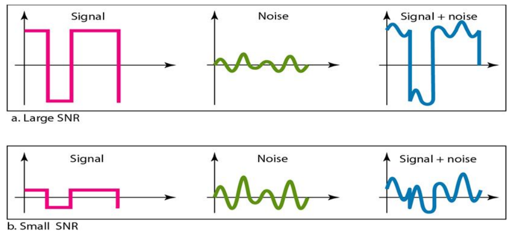

Figure 9. Two cases of SNR: a high SNR and a low SNR

The average signal power and the average noise power because these may change with time. "Fig. 9" shows the two cases of SNR. SNR is the ratio of what is wanted (signal) to what is not wanted (noise). The signal is less corrupted by noise mean high SNR; the signal is more corrupted by noise means low SNR.

V. Simulation Results & PSK Transceiver Using LabVIEW

In this paper we describe the simulation results of M- PSK transceiver system for a noisy channel. BER Vs Eb/N_0(db) for (4,8,16,32,64,128,256 bit PSK) is shown in "Fig. 10" & "Fig. 11" [17]. Output Results for Convolution coding and Turbo coding has been illustrated with the PSK parameters for Simulation being described in Table: 1. by taking a look at the output results we can very clearly say that Turbo coding gives a much improved and better minimization of the data errors than the Convolution coding. The simulation results conclude that smaller values of BER achieved using Turbo coding is in the range of 10-8 as compared to that of Convolution coding which is in the range (10-7) at a particular value of SNR. Hence, even at minimum values of SNR, the BER achieved is extremely small. With the help of this design we can also show that how fast and we can build a PSK transceiver for Software Defined Radio.

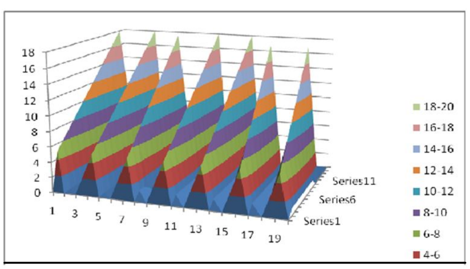

Figure 10. BER Vs E_b/N_0 (db) (4, 8,16,32,64,128,256 bit FSK) Output Results for Convolution coding.

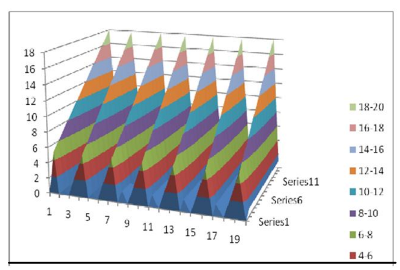

Figure 11. BER Vs E_b/N_0 (db) (4, 8,16,32,64,128,256 bit FSK) Output Results for Turbo coding.

VI. Simulation Results & of FSK Transceiver Using LabVIEW

This paper provides the design and simulation of the FSK Transceiver system for noisy channel. From the simulation results it can be seen that wireless system designed using FSK technique which has the major advantage in terms of Bit Error Rate providing high data rate and SNR using Frequency Shift Keying Modulation technique which concludes that data errors can be minimized using coding techniques, hence improving Signal to noise ratio (SNR).Thus, the signal can be recovered with very less data error at the destination. The performance of 2, 4 and 8-level FSK systems in additive white Gaussian noise channel is evaluated and compared on the basis of the simulations in Lab-VIEW as shown in figures.

In this simulation, the BERs are obtained by varying the values of Eb/No in the range of 2 to 16 the table 1 shows simulation Parameters.

TABLE I. SIMULATION PARAMETERS.

Sl. No.	Parameters that can be Decided by the User	Values taken by the user
1	PN sequence order	15 or any Value for MPSK & 9 or any Value for MFSK
2	Eb/No	80 dB or any Value
3	Message symbol	1000 or any Value
4	Transmission B.W (BT)	0.5 or any Value
5	Symbol Phase Continuity	Continous
6	FSK fequency deviation (Hz)	25KHz or any Value
7	Filter used	Gaussian, Root Raised Cosine Filter, Root Raised Cosine Filter
8	Symbol Rate	100.00 KHz
9	Eb/No Sample	5 or any Value
10	Sample per symbol	16 or any Value
11	Modulation Index	0.5 or any Value
12	BER vs Eb / No (without filter)	None
13	Current Eb/No	16 dB

BER vs SNR of FSK modulation scheme for different values of M is shown in “Fig. 12”.

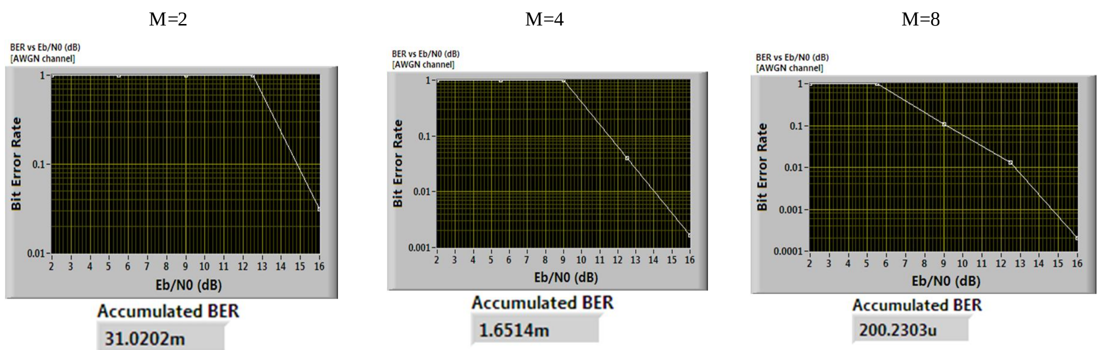

Figure 12. BER vs SNR of FSK modulation scheme for different values of M.

Bandwidth efficiency defined as R_b/B bits per second per Hertz or [(2log2M/M)], where R_b is the data rate in bits per second, and B is the channel bandwidth.
Case1: When η_B<<1,
Bandwidth of the channel is large (relative to R_b), and the main concern is limitation on power. This case is referred to as power-limited case. Signaling schemes, with high dimensionality, such as simplex, orthogonal, and bi-orthogonal, are frequently used in these cases.
Case2: when η_B>>1,
Bandwidth of the channel is small (relative to R_b), and therefore is referred to as the bandwidth – limited case. In these case low dimensional signaling schemes with crowed constellations, for example, 256-QAM (Quadrature amplitude modulation), are implemented [7].

VII. CONCLUSION

In this paper we discuss the simulation results of the M-PSK transceiver for noisy channel. From the results it becomes clear that the wireless communication system designed based on PSK technique provide high data rate and SNR. This can be clearly seen in terms of the BER Vs E_b/N_o output graph. We can also see clearly with these results that data errors can be minimized using coding techniques, which in turn improves the Signal to noise ratio (SNR) further, we can also say looking at the results that Turbo coding gives a much improved and better minimization of the data errors that the Convolution coding. The performance of M-

level PSK systems (4,8,16,32,64,128,256) for additive white Gaussian noise channel (AWGN) has been evaluated and compared on the basis of the simulations in LabVIEW as shown in Figure 13 & Figure 14. In this paper shown that how fast and effectively we can build a PSK transceiver for Software Defined Radio. With the help of this design we are able to see that data errors can be minimized using coding techniques, which in turn improves the Signal to noise ratio (SNR). Also we can say by looking at the results that Turbo coding gives a much improved and better minimum of the data errors than the Convolution coding.
In this paper, it is shown how Lab-VIEW can be used to build a FSK Transceiver for cognitive radio system & PSK Transceiver for software defined radio. In particular, an FSK/PSK Transceiver system consisting of a message source, a pulse shape filter, a modulator, demodulator, a frame synchronizer, a phase continuity and frequency deviation was built in the graphical programming environment of Lab-VIEW. The use of Lab-VIEW allowed this interactive cognitive radio system to be built in a shorter time as compared to text-based programming languages.
The simulation results shows in terms of BER and SNR using Phase Shift Keying Modulation technique which concludes that data errors can be minimized and increasing M decreases BER and decreases bandwidth efficiency and for FSK Modulation technique which concludes that date errors can be minimized and increasing M increases BER and increases bandwidth efficiency using coding techniques, hence improving Signal to noise ratio the signal can be recovered with very less probability of error with the increase in the M (number of levels) at the destination.

FUTURE WORKS

This project discussed the performance of Frequency Shift Keying (FSK) Phase Shift Keying (PSK) process base band modulation techniques in the normal AWGN channel. This work can extended to
(i) Evaluate the performance of FSK/PSK process with other adaptive modulation techniques like MQAM, GMSK etc. in fading channels like Ricean, Nakagami fading channel.
(ii) To improve the BER performance some channel coding techniques such as BCH code, Reed-Solomon code and Convolution code can be used with proposed FSK model.
(iii) Future work of project includes the further development of hardware implementation using Universal Software Radio Peripheral (USRP) for performance test and evaluation of a next-generation cognitive radio network.

REFERENCES

[1] RituKhullar, Sippy Kapoor, Naval Dhawan, “Modulation technique For Cognitive Radio, Applications”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 3, May-Jun 2012, pp. 123- 125.

[2] Amanpreet Singh Saini, “The Automated Systems For Spectrum Occupancy Measurement And Channel Sounding In Ultra-Wideband, Cognitive Communication, And Networking” Master of Science in Electrical Engineering, August 2009.

[3] Ahmed Barnawi, “Wideband Sensing for Cognitive Radio Systems in Heterogeneous Next Generation Networks” International Journal of Computer Networks (IJCN), Volume (3): Issue (2): 2011.

[4] Hans-Petter Halvorsen,”Introduction to LabVIEW” 012.04.20

[5] N.Kim, N.Kehtarnavaz, M. Torlak,” LabVIEW-Based Software-Defined Radio: 4-QAM Modem” systemics, cybernetics and informatics volume 4 - number 3.

[6] Md. Abir Hossain Khandokar, Md. Golam Rashed, “Performance Comparison of M-Ary Modulation Schemes for an Efficient Wireless Communication System with Digital Color Image Transmission”, Department of Information and Communication Engineering, University of Rajshahi, Rajshahi, Bangladesh.

[7] Eric Nii Otorkunor Sackey, “Performance Evaluation of M-ary Frequency Shift Keying Radio Modems via Measurements and Simulations “Department of Electrical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden, September 2006.J. Mitola III,”Software Radios –Survey, Critical Evaluation and Future Directions,” in Proc. National Telesystems Conference, 1992, pp. 13/1513/23.

[8] Nikhil Marriwala, O. P. Sahu, Anil Vohra,: “8-QAM Software Defined Radio Based Approach for Channel Encoding and Decoding Using Forward Error Correction”, Wireless Personal Communications, 1st May-2013, Springer US, 10.1007/s11277-013-1191-z.

[9] Nikhil Marriwala, O. P. Sahu, Ritu Khullar and Anil Vohra, “Software Defined Radio (SDR) 4-bit QAM Modem using LabVIEW for Gaussian Channel”CIIT International Journal of Wireless Communication”. March 2011.

[10] W. Tuttlebee, Software Defined Radio: Baseband Technologies for 3G Handsets and Base Stations, John Wiley & Sons, 2004.
[11] Friedrich K. Jondral “Software-Defined Radio—Basics and Evolution to Cognitive Radio” (EURASIP Journal on Wireless Communications and Networking 2005:3, 275–283).
[12] N. KIM, N. KEHTARNAVAZ, and M. TORLAK LabVIEW-Based Software-Defined Radio: 4-QAM Modem Proceedings of ICASSP, vol. 2, 2006, pp. 985-988.
[13] Eric Nicollet and Lee Pucker, “Standardizing Transceiver APIs for Software Defined and Cognitive Radio”, www.rfdesign.com, February 2008,
[14] Hiroyasu Ishikawa, “Software Defined Radio Technology for Highly Reliable Wireless Communications,” Wireless Personal Communications, 64 (2012), 461–72 dx.doi.org/10.1007/s11277-012-0596-4.
[15] P. Prakasam and M. Madheswaran, “Intelligent Decision Making System for Digital Modulation Scheme Classification in Software Radio Using Wavelet Transform and Higher Order StatisticalMoments,” WirelessPersonalCommunications,50 (2008),509–28, dx.doi.org/10.1007/s11277-008-9621-z.
[16] A.S Kang, Vishal Sharma, “Pulse Shape Filtering in Wireless Communication-A Critical Analysis”, (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 2, No.3, March 2011.
[17] Nikhil Marriwala, Om Prakash Sahu, Anil Vohra, “LabVIEW based design implementation of M-PSK transceiver using multiple Forward Error Correction coding technique for Software Defined Radio applications” (JEEE) Journal of Electrical and Electronic Engineering, 2014; 2(4): 55-63, published online November 14, 2014, doi: 10.11648/j.jeee.20140204.11, ISSN: 2329-1613 (Print); ISSN: 2329-1605 (Online).
[18] Ian F. Akyildiz, Won-yeol Lee, Mehmet C. Vuran, “A survey on spectrum management in cognitive radio networks” IEEE Communications Magazine (Volume: 46, Issue: 4, April 2008), 03 April 2008, ISSN: 0163-6804.