A Chaos based PN Sequence Generator for Direct-Sequence Spread Spectrum Communication System.

Deb Sunder Swami and Kandarpa Kumar Sarma.

Abstract—In this paper, a pseudo-random noise(PN) sequence generator is constructed exploiting the features of one-dimensional chaotic systems such as the logistic map. The use of logistic map is done in a novel manner to generate strong cryptographic sequence. The method, the logistic map scheme, is applicable for use on wireless networks because it requires simple devices to generate the sequence. The method is shown to achieve reliability from theperspective of communication agents, as well as unpredictability and randomness from the perspective of an eavesdropper. Lastly, the performance of the scheme is compared against that of existing techniques. Results from a comparative analysis indicate that the proposed method generally yields a greater number of reliable, unpredictable and random bits than existing techniques under the same conditions.

Keywords—DSSS modulation, logistic map, PN sequence, Kasami sequence, AWGN channel, Rayleigh channel, BPSK modulation, QPSK modulation, DPSK modulation.

I. Introduction

In this era of modern communication technologies, people exchange information with each othervia wired or wireless networks. To avoid unauthorized access and illegal usage of information being transferred over the insecure communicationchannel, the security systems need to be deployed.Cryptographic techniques are used to provide necessary safety to the user's sensitive data againstillegal usage. The challenging task in the design of cryptographic techniques is to generate sequences with high randomness and proper statistical properties. Pseudo-random sequences, generated by encryption techniques of security systems, quality determine its strength from a cryptographic viewpoint. Apart from cryptography, PN sequences are equally applicable and significant in the areas of directsequence spread spectrum (DSSS), statistical sampling,computer simulation, etc. Linear feedback shiftregisters (LFSR) based PN sequence generators are verywell suited for hardware realizations. LFSR-basedgenerators are simpler in implementations, havehigh speed performance and satisfactory statistical properties. However, the disadvantage withLFSR based design is that the feedback tapingscan be determined under Berleykamp Massey attack. The importance of careful design of PN Sequence generators cannot be underestimated asthese generators can be particularly useful to ensure proper spreading of modulated data in directsequence spread spectrum modulation. Generating high quality randomness is a vital part of aPN sequence generator [1][2].

In the recent past, the behavior of chaoticsystems has been much studied and analyzed.According to the chaos theory, chaotic systemsare nonlinear dynamical systems whose stateevolves with time [5]. The future dynamics ofthese systems are fully defined by their initial conditions. As a result, the behavior of these systems appears random. It has been determinedthat the chaotic systems have some interesting inherent characteristics such as high dependency onits initial conditions, unstable periodic orbits withlong period, ergodicity, etc. Due to these characteristics, chaotic systems are adopted as promising candidates for designing of PN sequence generators. Chaos based encryption methods provides cryptographically better protection than theconventional cryptographic techniques. Keeping these points under consideration, the characteristics of the chaotic systems are exploited tobuild a chaos based PN sequence generator, whichcan ascertain excellent statistical and randomness performance. The simple one-dimensionalchaotic logistic maps are used to generate real valued chaotic sequences, which on pre-processingand quantization give a PN sequence that hasnoise-like characteristics.[1] To test the performance, the proposed chaos-based PN sequence istested on a multipath environment using Rayleighand AWGN channels with three different modulation schemes, viz. Binary Phase Shift Keying(BPSK) Quadrature Phase Shift Keying (QPSK), and Differential Phase Shift Keying (DPSK) modulation.Rest of the paper is organized as follows: theproposed chaos-based PN sequence generator isdiscussed in Section II. The Experimental detailsand the Results are given in Sections III, whilethe conclusions are drawn in Section IV.

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II. Proposed Logistic map based PN Sequence Generator

The one-dimensional logistic map is used to construct the proposed PN sequence generator. Theone dimensional logistic map is used to produce real-valued chaotic sequences. The simple logistic map is defined by the equation (1).

$$x(n + 1) = \lambda x(n) (1 - x(n)) \quad (1)$$

Wherex(0) is initial condition, λ is the systemparameter and n is the number of iterations. Theresearch shows that the logistic map is chaotic for3.57 $<\lambda<$ 4 and 0< x(n) < 1 for all n $\geq$ 0. As isclear from their state equations, the value of statevariable obtained onk^{th} iteration will acts as seedfor the next $(k + 1)^{th}$ iteration. The dynamicalorbits of chaotic maps highly deviated from theirnormal trajectories, which impart randomness tothe generated chaotic sequences. The diagram ofthe proposed PN sequence generator is shown in Figure 1.

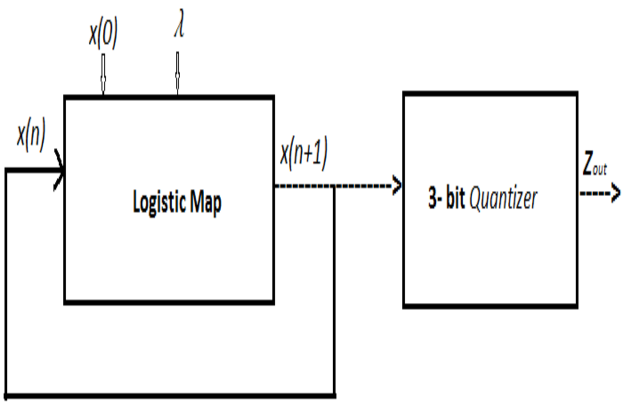

Figure 1: Proposed PN Sequence Generator

As shown in the Figure 1 above, x(0) and λ arefeed to the system as initial seeds. On each iteration, the real valued state variable $x_i(n)$ of chaoticmap is captured and preprocessed/quantized intoa 3-bit value. So, for each real-valued chaotic sequence $x_i(n)$, we get a binary random sequence$Z_i(n)$. After the quantization step, the sequence ofa predefined length is used for spreading of modulated data.

A. Direct-Sequence Spread-Spectrum

Direct Sequence Spread Spectrum (DSSS) is aspread spectrum technique whereby the originaldata signal is multiplied with a pseudo randomnoise spreading code. This spreading code has a higher chip rate which results in a wideband timecontinuous scrambled signal. DSSS significantlyimproves protection against interfering (or jamming) signals, especially narrowband and makesthe signal less noticeable. It also provides security of transmission if the code is not known to the public. The effect is to diffuse the information in alarger bandwidth. Conversely, we can remove thespread-spectrum code (called a despreading operation) at a point in the receive chain before dataretrieval. A despreading operation reconstitutesthe information into its original bandwidth. Obviously, the same code must be known in advanceat both ends of the transmission channel.

Figure 2 shown below shows a setup of DSSSmodulation. Here the logistic map based PN sequence is used for spreading the transmitted data.At the receiver end the same PN sequence is usedto despread the data before demodulating it.

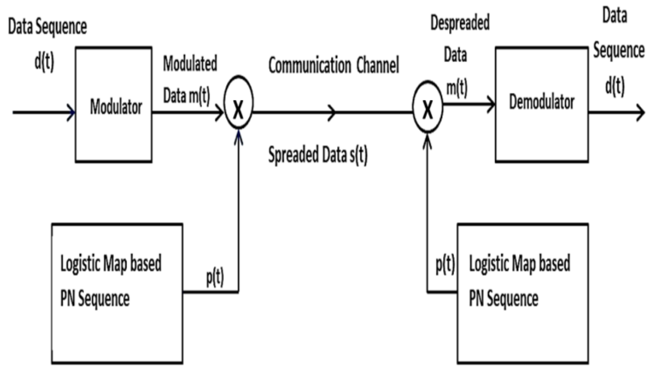

Figure 2: DSSS Modulation Scheme

B. Validation of Proposed Sequence in DSSS Scheme.

To check the performance of the logistic mapPN sequence generated, the spreaded data istested in a multipath environment with Rayleighand AWGN channel and three different modulation schemes. The comparison is made withKasami sequence and existing LFSR based PNsequence. In the first simulation, the logistic mapbased PN sequence is used to spread BPSK modulated data in a multipath AWGN channel. BPSKis a method for modulating a binary signal ontoa complex waveform by shifting the phase of thecomplex signal. In digital baseband BPSK, thesymbols 0 and 1 are modulated to the complexnumbers exp(jt) and -exp(jt), respectively, wheret is a fixed angle or the phase offset. The output from the BPSK modulator is multiplied withthe logistic map based PN sequence generated,to spread the data. Next, the spreaded data ispassed through a multipath AWGN channel. TheAWGN channel adds white Gaussian noise to a real or complex signal. Then the signal is despreaded and the individual paths are combinedin terms of power or gain. The despreaded datais then demodulated using BPSK demodulator. Finally the BER of the signal is calculated. Thesame procedure is done with the LFSR based PNsequence and Kasami sequence. The BER curveis plotted for the three sequences in a SNR rangeof -10dB to +10dB. The PN sequence generator, generates a sequence of pseudorandom binary numbers using a linear-feedback shift register (LFSR). The LFSR is implemented usinga simple shift register generator (SSRG, or Fibonacci) configuration. Kasami sequence is also aPN sequence generated by a polynomial methodwith good correlation properties.

The above mentioned steps are repeated withQPSK and DPSK modulations. In case of QPSKfor input m, the output symbol is exp(jθ +jπm/2), where θ is the phase offset parameter forinput m. The M-DPSK modulates using the M-ary differential phase shift keying method. TheM-ary number parameter, M, is the number ofpossible output symbols that can immediately follow a given output symbol. The three spreading sequences are used in both modulation schemesand the results compared. In the following section, the experimental setup is provided and theresults shown. As will be shown later the logistic map scheme gives better error performancecompared to both PN sequence and Kasami sequence. For a Rayleigh channel also the abovesteps have been carried out. Rayleigh fading models assume that the magnitude of a signal thathas passed through such a communications channel will vary randomly, or fade, according to aRayleigh distribution{the radial component of thesum of two uncorrelated Gaussian random variables.} Here too the logistic map based spreadingchannel performed on expected lines and bettercompared to both PN sequence and Kasami sequence.

Next, the characteristics of the generated sequence is tested under different fading channels,viz. slow fading channel, fast fading channel andfrequency selective fading channel. The BERcurves are generated and their respective channelimpulse responses are shown for three differentmodulation schemes.

III. Experimental Setup and Results

The logistic map based PN sequence has beengenerated using MATLAB and the simulation hasbeen done on Simulink tool. The following initialconditions have been taken for the logistic map:x(0) = 0.1 and λ= 4. The auto-correlation function is one of statistical parameters used to assess the random nature of sequences, it has delta-function form for a perfectly pseudo random noisesequence. The auto-correlation function of PN sequence generated is shown in Figure. 3. It is clearfrom the figure that sequence generated by theproposed generator has moderate autocorrelation function form.

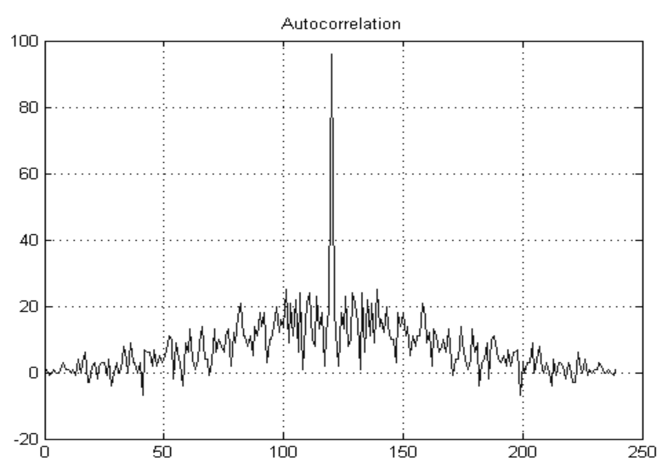

Figure 3: Autocorrelation Function of PN Sequence Generated

Using Simulink, the blocks have been arranged using standard communication criteria and all the three spreading sequences (logistic map PN sequence, LFSR basedPN sequence and Kasami sequence) has beentested in same conditions. The BER values fora SNR range of -10dB to +10dB has been obtained. The obtained BER values are then plottedusing MATLAB.

For calculating BER 2400 samples have beencompared. The BER curve for BPSK modulationin AWGN channel with comparison between threespreading sequences is provided in Figure 4. It isobvious from the figure that the logistic map PN sequence has better error performance comparedto the LFSR PN sequence and Kasami Sequence.

In the next setup the modulation scheme thatis used is QPSK. Here also the same conditionshas been used for the three spreading sequences.

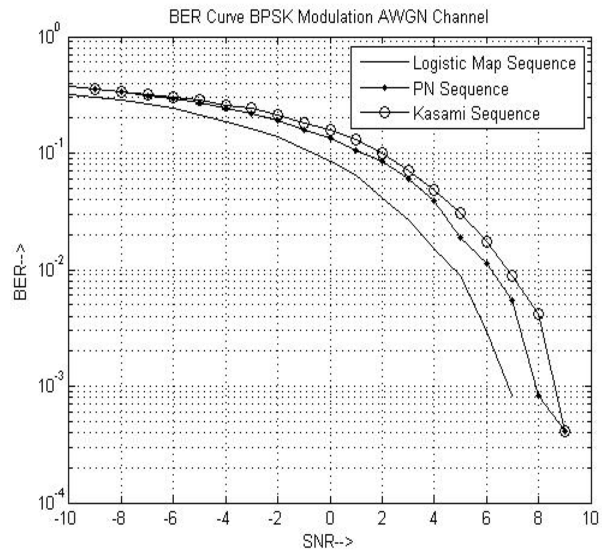

Figure 4: BER curve for BPSK Modulation.

Figure 5 shows the BER curve obtained. Here alsoit is clear that logistic map PN sequence providescomparatively better error performance and theoverall performance remains same. The LFSR PNsequence and the Kasami sequence have similarerror performance.

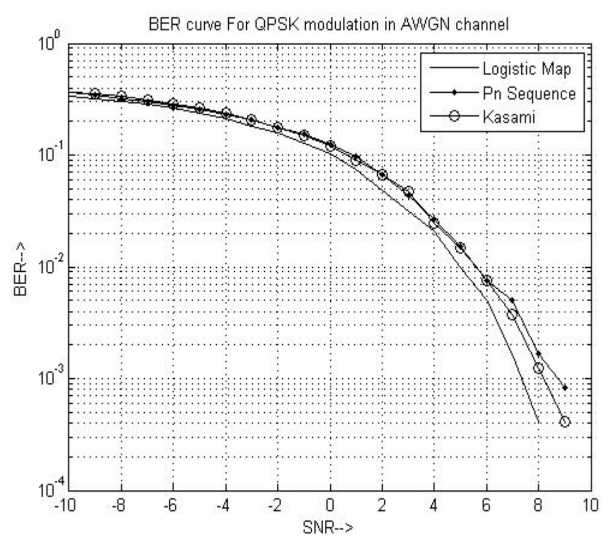

Figure 5: BER curve for QPSK Modulation.

Similarly, in the third setup, DPSK modulation scheme has been used using the same conditions. Figure 6 shows the BER curve obtainedfrom the setup. Again the logistic map PN sequence provides comparatively better error performance then the Kasamiand LFSR PN sequence. However, here the overall system performance is slightly degraded due to the differentialmodulation scheme used.

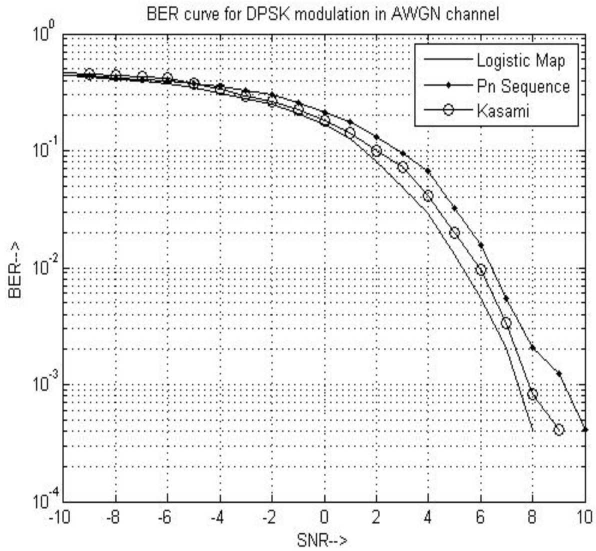

Figure 6: BER curve for DPSK Modulation.

As is obvious from the curves shown above,the logistic map PN sequence provides better error performance in a multipath environment.

In the next setup a Rayleigh fading channelhas been added to the model. The Rayleigh channel adds fading noise to the signal, and it accepts only complex inputs. For simulation simplicity the complex phase gains have been removed to maintain uniformity and multipath havebeen added externally. Rest of the criteria hasbeen kept same as the previous model. The simulations were done for BPSK, QPSK and DPSKmodulation schemes. The error performance forlogistic map PN Sequence, LFSR PN sequenceand Kasami sequence has been compared. Theirrespective BER has been plotted.

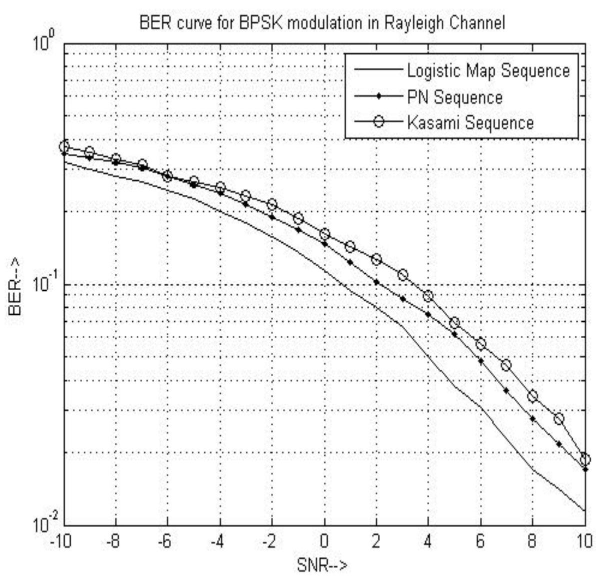

Figure 7: BER curve for BPSK Modulation in Rayleigh Channel.

Figure 7 shows the BER curve for BPSK modulation in Rayleigh channel. It can be seen thatthe logistic map PN sequence clearly gives bettererror performance then the other two spreadingsequences. But due to the presence of Rayleigh channel the fading is flat and the overall systemperformance degrades to some extent.

In the next simulation, QPSK modulationscheme has been used. Here also the same conditions have been used for the three spreading sequences. Figure 8 shows the BER curve obtained.Here also it is clear that logistic map PN sequenceprovides comparatively better error performanceand the overall performance remains same. TheLFSR PN sequence and the Kasami sequence havesimilar error performance.

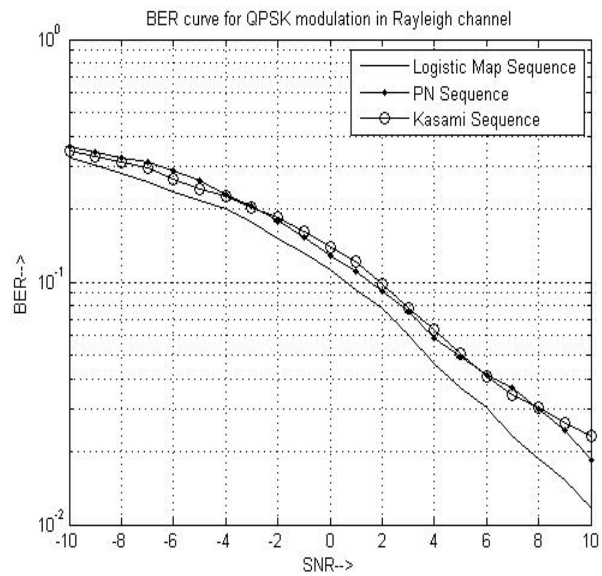

Figure 8: BER curve for QPSK Modulation in Rayleigh Channel.

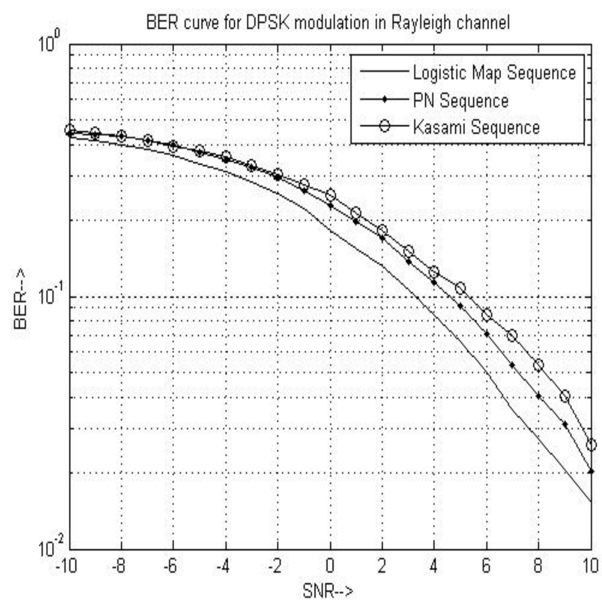

Figure 9: BER curve for DPSK Modulation in Rayleigh Channel.

In the final simulation DPSK modulationscheme has been used using the same conditions.Figure 9 shows the BER curve obtained from thesetup. Again the logistic map PN sequence provides better error performance then the Kasamiand LFSR PN sequence.

From the above simulations it is clear that theproposed logistic map based PN sequence givesbetter error performance then both LFSR basedPN sequence and Kasami sequence. A comparison was also made with Hadamard code and BER performance obtained for the logistic map PN sequence was much better than the Hadamard code.

In the next setup the fading characteristicsof a wireless communication channels is verifiedusing the logistic map based spreading sequence. The different fading characteristics tested are asdescribed below.

A. *Fading Channels*

The type of fading experienced by a signal propagating through a mobile radio channel dependson the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters (such as bandwidth, symbol period, etc) andthe channel parameter (such as RMS delay spreadand Doppler spread), different transmitted signalswill undergo different types of fading. The timedispersion and frequency dispersion mechanismsin a mobile radio channel lead to four possibledistinct effects, which are manifested dependingon the nature of the transmitted signal, the channel, and the velocity[6].

- Flat Fading: If the mobile radio channel has aconstant gain and linear phase response over abandwidth which is greater that the bandwidthof the transmitted signal, then the received signal will undergo °at fading. In °at fading, themultipath structure of the channel is such thatthe spectral characteristics of the transmittedsignal are preserved at the receiver. Howeverthe strength of the received signal changes withtime, due to fluctuations in the gain of the channel caused by multipath.Flat fading channels arealso known as amplitude varying channels andare sometimes referred to as narrowband channels, since the bandwidth of the applied signalis narrow as compared to the channel flat fadingbandwidth.
- Frequency Selective Fading: If the channelpossesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, the channel creates frequency selective fading on the received signal.Under such conditions the channelimpulse response has a multipath delay spreadwhich is greater than the reciprocal bandwidthof the transmitted message waveform. Whenit occurs, the received signal includes multipleversions of the transmitted waveform that areattenuated and delayed, and hence the receivedsignal is distorted. For instance, the fading typein GSM system is frequency selective.
- Fast Fading: In a fast fading channel, thechannel impulse response changes rapidly withinthe symbol duration. That is, the coherencetime of the channel is smaller than the symbolperiod of the transmitted signal. Viewed in thefrequency domain, signal distortion due to thisincreases with increasing Doppler spread relative to the bandwidth of the transmitted signal.
- Slow Fading: In a slow fading channel, thechannel impulse response changes at a ratemuch slower than the transmitted baseband signal S(t). In the frequency domain, this impliesthat the Doppler spread of the channel is muchless than the bandwidth of the baseband signals.

The above mentioned characteristics of a wirelesscommunication channel were tried using the logistic map based PN sequence in a Rayleigh fadingchannel. The BER curves and the channel impulse responses shown below justify the characteristics for the above mentioned channels. Formodeling slow fading and fast fading channels,Doppler frequencies of 10 Hz and 110 Hz has beenused respectively. For modeling a frequency selective fading channel, a delay vector with differentdelays and path gains has been used.

The BER performance of slow fading channelis marginally better because of the dependenceon the lower Doppler frequency value, shown in Figure 10.

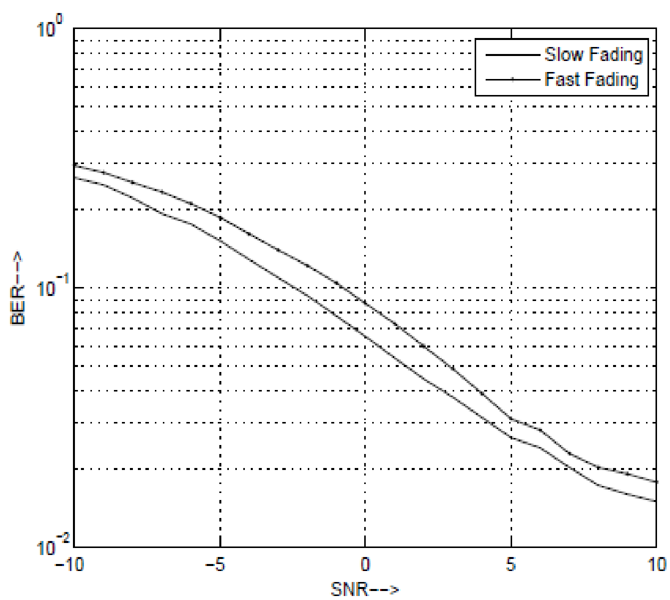

Figure 10: BER curve showing flat fading versus slow fading for BPSK..

The channel impulse response of both thecases is shown in Figure 11 and Figure 12 below which showed that in a fast fading channelthe channel impulse response changed at a muchfaster rate compared to a slow fading channel.

The BER curves shown in Figure 13 show thatfrequency selective fading is the worst case scenario and as such a equalization technique hasbeen used to compensate for the performance.

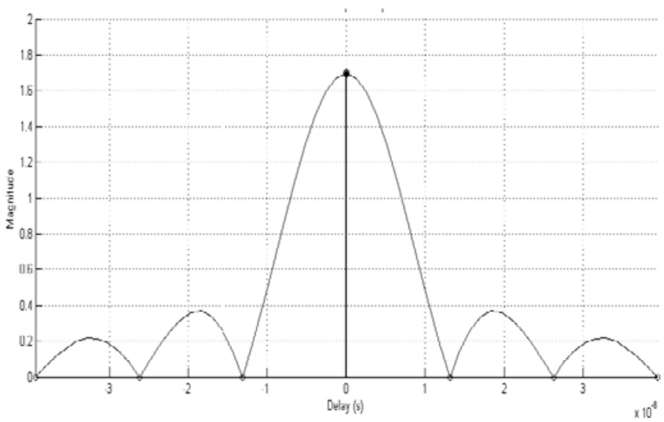

Figure 11: Channel Impulse response for slow fading channel.

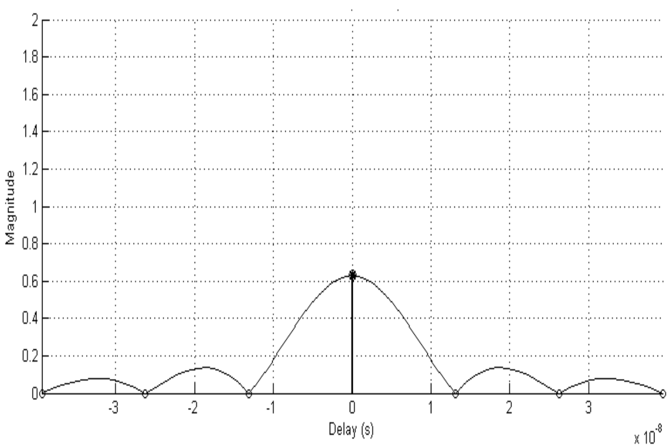

Figure 12: Channel Impulse response for fast fading channel.

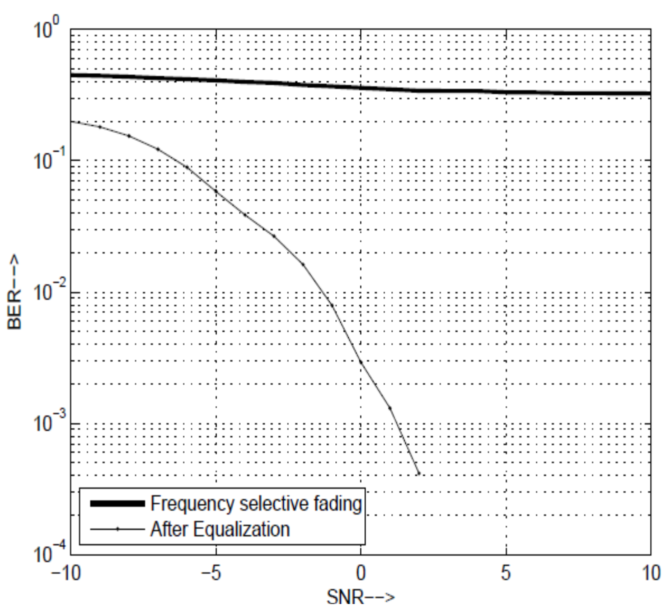

Figure 13: BER curve showing frequency selectivefading.

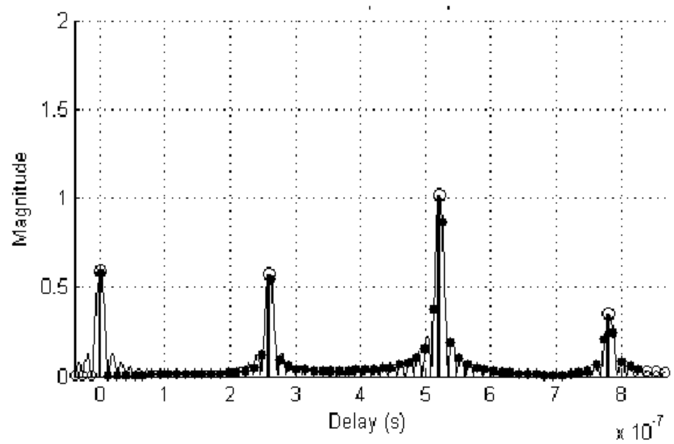

Figure 14: Channel Impulse response for frequency selective fading channel.

For a frequency selective fading case the channel impulse response is shown in Figure 14. Theimpulse response has a multipath delay spreadwhich is greater than the reciprocal bandwidthof the transmitted message waveform. When itoccurs, the received signal includes multiple versions of the transmitted waveform that are attenuated and delayed, and hence the received signalis distorted.

The same procedures were carried for QPSKand DPSK modulation schemes as well. ForQPSK modulation, Figure 15 shows slow fadingand fast fading channel BER curves. Here as well,the slow fading channel has significantly better error performance compared to a fast fading channel because signal distortion due to fast fadingincreases with increasing Doppler spread relativeto the bandwidth of the transmitted signal.

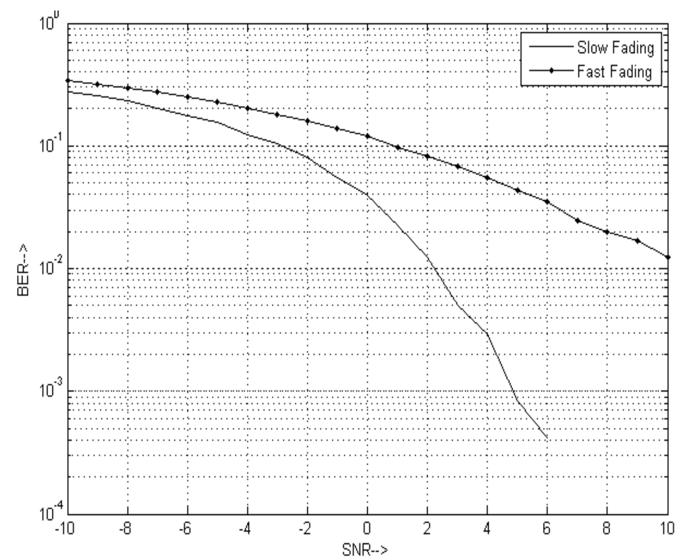

Figure 15: BER curve showing flat fading versus slow fading for QPSK..

Their respective channel impulse responses are shown in Figure 16 and Figure 17 where it was observed thatin a fast fading channel the channel impulse response changed at much faster rate compared toslow fading channel. Similarly for QPSK, the BER curve for frequency selective fading channel is shown in Figure 18 which presents the worst casescenario. As such equalization is used to improvethe BER performance. The channel impulse response is shown in Figure 19, under this conditionthe channel impulse response had multipath delayspread.

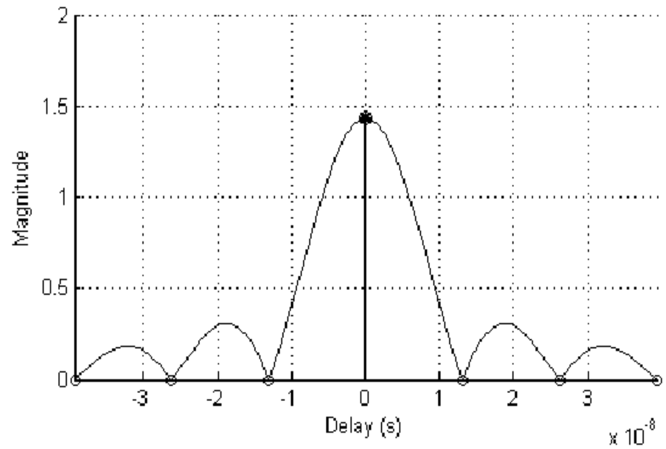

Figure 16: Channel Impulse response for slow fading channel.

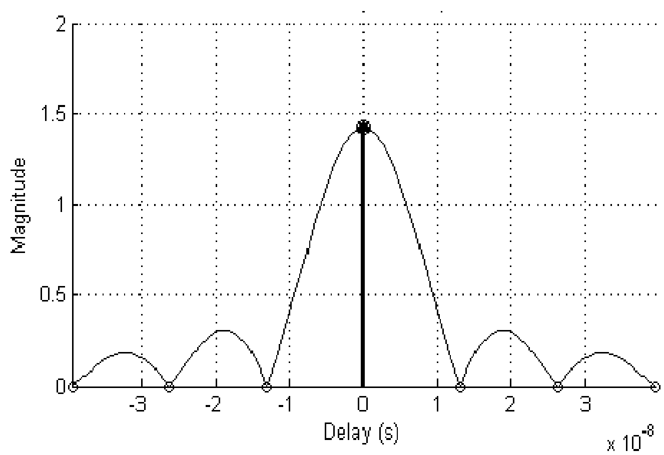

Figure 17: Channel Impulse response for fast fading channel.

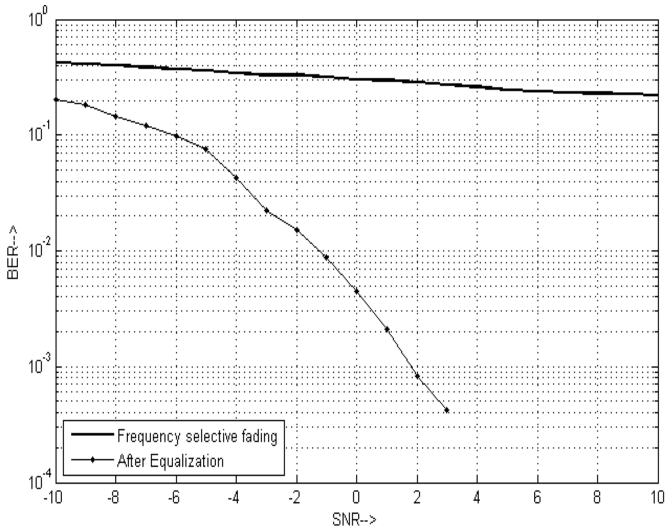

Figure 18: BER curve showing frequency selectivefading.

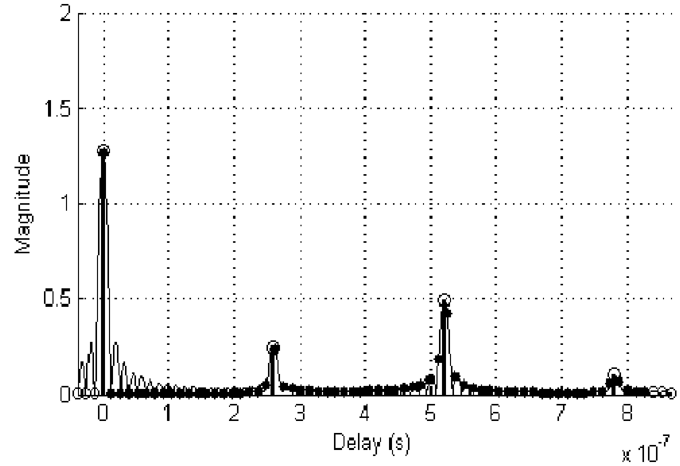

Figure 19: Channel Impulse response for frequency selective fading channel.

The above procedures were carried for DPSKmodulation schemes too. For DPSK modulation, Figure 20 shows slow fading and fast fading channel BER curves. Here as well, the slow fadingchannel has better error performance compared to a fast fading channel because signal distortion dueto fast fading increases with increasing Dopplerspread relative to the bandwidth of the transmitted signal.

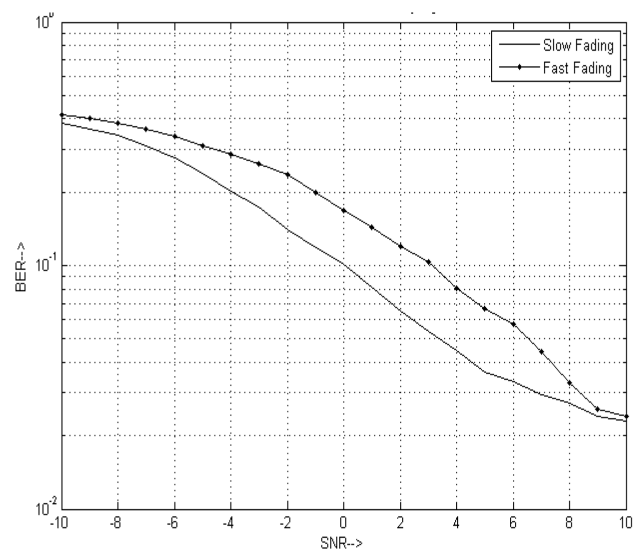

Figure 20: BER curve showing flat fading versus slow fading for DPSK..

Their respective channel impulse responses are shown in Figure 21 and Figure 22 wherehere also it was observed that in a fast fadingchannel the channel impulse response changed atfaster rate compared to slow fading channel. Itis clear that the velocity of the mobile(or velocity of objects in the channel) and the basebandsignaling determines whether a signal undergoesfast fading or slow fading.

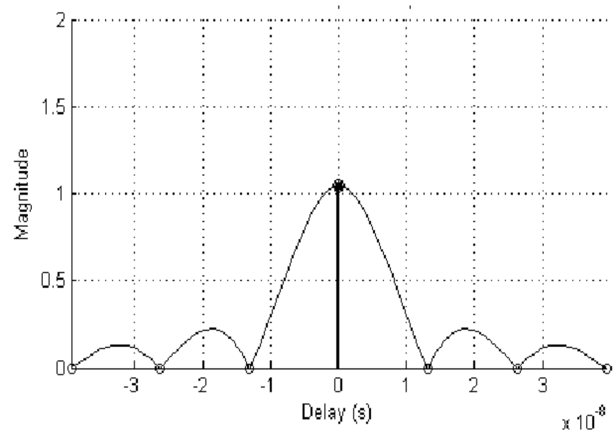

Figure 21: Channel Impulse response for slow fading channel.

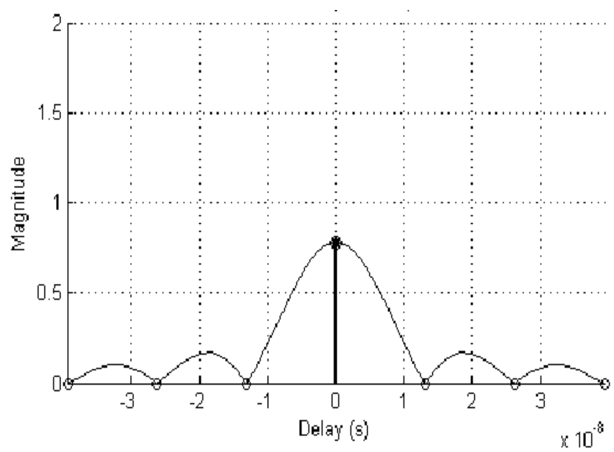

Figure 22: Channel Impulse response for fast fading channel.

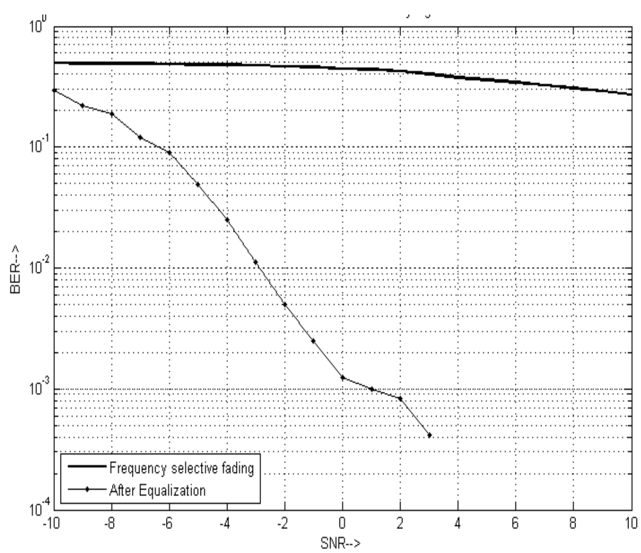

Figure 23: BER curve showing frequency selectivefading.

Similarly for DPSK, the BER curve for frequency selectivefading channel is shown in Figure23 which presents the worst case scenario, as suchequalization is used to improve the BER performance. The channel impulse response is shownin Figure 24, under this condition the channel impulse response had multipath delay spread.

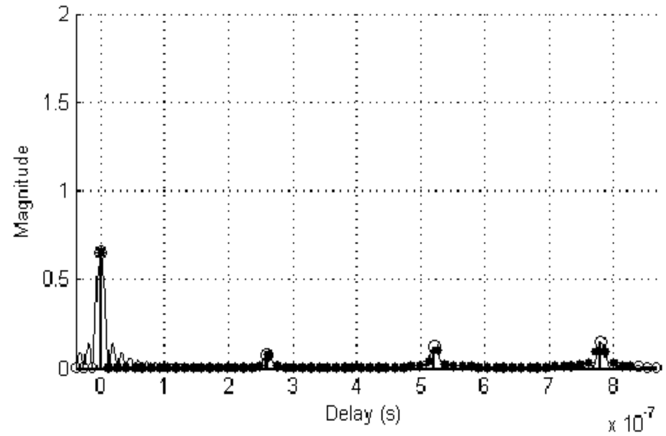

Figure 24: Channel Impulse response for frequency selective fading channel.

From the above simulations we can say thatwhen a channel is specified as a fast fading or slowfading channel, it does not specify whether thechannel is flat fading or frequency selective fading in nature. Fast fading channel only deals withthe rate of change of the channel due to motion.Hence a flat fading, fast fading channel is a channel in which the channel impulse response is approximated to be a delta function (no time delay).In case of frequency selective channel, the amplitudes, phases, and time delays of any one of themultipath components vary faster than the rateof change of the transmitted signal [6].

In the final simulation a comparative studyhas been done between logistic map based spreading sequence, LFSR based PN sequence andKasami sequence under slow and fast fading channels conditions. The BER curves for slow and fast fading channels are shown Figures 26 and 27. It isclear from the Figures shown below that the logistic map based spreading sequence performs better than both the LFSR based PN sequence andKasami sequence.

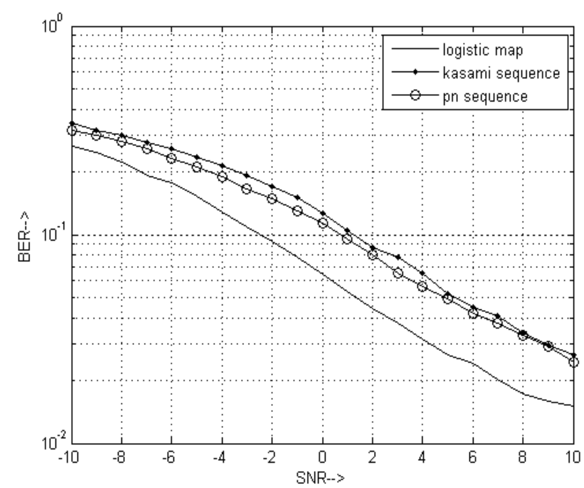

Figure 25: BER curvesin slow fading channel.

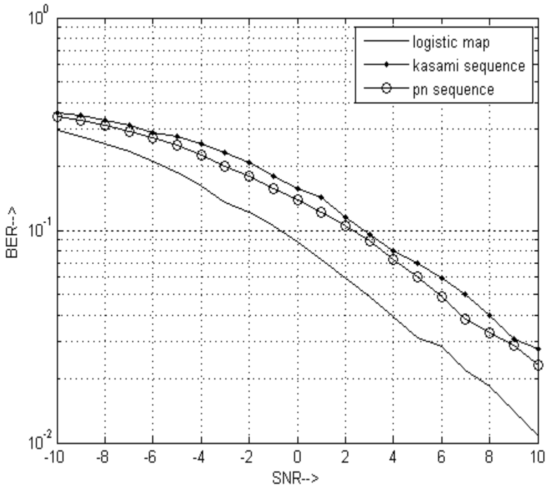

Figure 26: BER curvesin fast fading channel.

Certain computational complexities were encountered during the simulations. Firstly, sincethe spreading sequence was generated in Matlab.An "Embedded Matlab Function" block was usedto generate the spreading sequence. Sequence indexing had to be used in this block to get all the quantized bits concatenated. Secondly, a lot ofadditional blocks like "real to complex' were usedto negate port mismatches. Due to these additional blocks simulation process became slower.Generation of the spreading sequence was also anissue because the iterated values from the logistic equation are fractional numbers. As such binary conversion was difficult because decimal tobinary conversion of fractional numbers directlywould not have yielded the exact spreading sequence length. So, 3-bit quantization was used toconvert the iterated values from the logistic equation into binary.

IV. Conclusion

A logistic map based PN sequence generator isproposed in this paper. The generator employedone dimensional chaotic logistic map to generate a PN sequence. The generated sequence wasused as a spreading sequence in a direct sequencespread spectrum modulation multipath environment with AWGN and Rayleigh fading channels.The BER curves were obtained and comparedwith the existing LFSR-based PN sequence generator and Kasami sequence. The comparativestudy reveals that proposed generator performsbetter than both. The generated sequence wasthen tested under various channel fading conditions. Their respective BER curves and channelimpulse responses were generated and upon comparison with theoretical standards, the sequence

was found to perform under expected lines. Also acomparative study was done between logistic mapbased PNsequence, LFSR based PN sequence andKasami sequence under slow and fast fading conditions. The BER curves obtained showed thatthe logistic map based PN sequence performedbetter than both the other sequences. Hence,wecan say that the PN sequence generated is cryptographically strong and can be applied for DirectSequence Spread Spectrum (DSSS) Modulation.

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V. VI REMARKS

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VI. APPENDIX

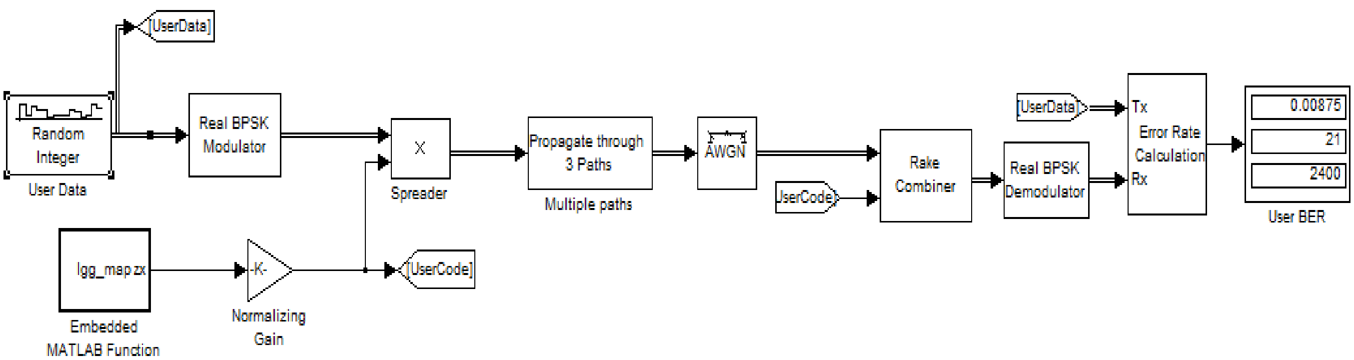

Figure 27: System model for AWGN Channel.

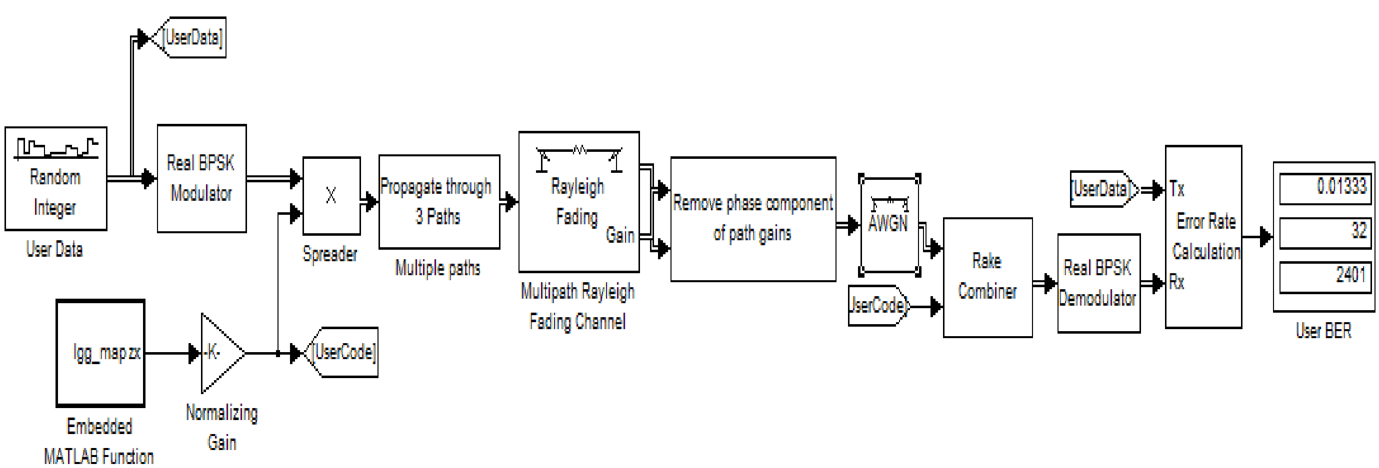

Figure 28: System model for Rayleigh Channel.