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PERFORMANCE COMPARISON OF SPREAD SPECTRUM MODULATION FOR WIRELESS CHANNELS USING ANN – ASSISTED PSEUDO - NOISE SEQUENCE GENERATOR

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Abstract- One of the challenging issues in Spread-Spectrum Modulation (SSM) is the design of the Pseudo – Random or Pseudo - Noise (PN) sequence generator. Though several approaches are available that deals with the PN – sequence generator, there always exists the possibility of exploring the use of innovative methods through which shortcomings of the known techniques can be minimized and the performance of communication systems using SSM improved. This work is related to the use of Artificial Neural Network (ANN) for generation of the PN sequence during transmission and reception of a SSM based system. The benefit of the ANN - assisted PN generator shall be that it will simplify the design process of the PN - generator and yet provide high reliability against disruptions due to intentional disruptions and degradation of signal quality resulting out of variations in channel condition. The experiments carried out show that the ANN - assisted system is robust enough to deal with the unpredictability in the wireless channels and provide satisfactory performance under Gaussian and Rayleigh /Rician fading. The performance of the SSM system can be further enhanced by the use of coding. Hamming and cyclic redundancy check (CRC) codes have been used here with the data stream to explore if performance of the SSM system is improved further.

Keywords- *SSM, PN sequence, DS, FH, ANN, BER, Rayleigh, Rician.*

I. INTRODUCTION

Spread spectrum Modulation (SSM) is a transmission technique in which a Pseudo-Noise (PN) code independent of the information data is used as a modulation waveform to spread the signal energy over a bandwidth much greater than the signal information bandwidth. This technique decreases the potential interference to other receivers while achieving privacy [1].The receiver correlates the received signals to retrieve the original information signal.

For the SSM system performance of the spread spectrum communication, the processing gain of the spreading code is one of major concern. The processing gain depends on the code length of the spreading code. The larger the processing gain the better is the system performance [2]. This is dependent on the PN sequence to be used for the SSM. This work considers a PN sequence generator by shift-registers and the one assisted by Artificial Neural Network (ANN) for transmission and reception. A direct sequence spread spectrum signal is generated by the direct mixing of the incoming data with a spreading waveform before the final carrier modulation. But in frequency hopping the spectrum of a data-modulated carrier is widened by changing the carrier frequency in a pseudo-random manner over a sequence of frequencies called the frequency hopping pattern [3][4][5][6]. A generic SSM setup with both DS and FH approaches is depicted in the Fig. 1 and Fig. 2.

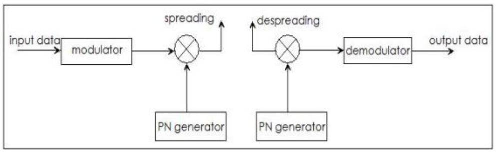

Figure 1 : Direct sequence spread spectrum system

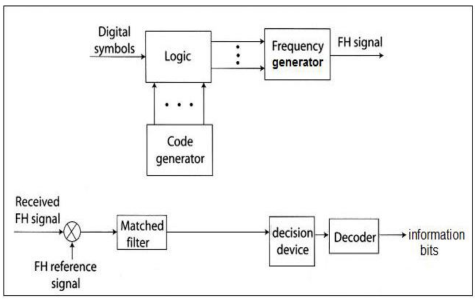

Figure 2 : FHSS transmitter and receiver

II. SYSTEM TYPE

The system model is depicted in Fig. 3. It is constituted by a SSM transmitter with a PN sequence generator formed by an ANN. The receiver is also assisted by an ANN. The ANN is trained to generate the unique PN sequences which are used for transmission and reception of specific data blocks. The core of the system is the ANN. The most important difference with respect to classical information processing techniques is that ANNs are not mathematically programmed, but are trained with examples. It means that the solution of practical problems of which the mathematical equation is unknown, can be approximated, with only some sample data and corresponding solutions [7]. The system model implemented in this work is depicted in the Fig. 3 and has the following components.

A. *Creation*

A feed-forward ANN is created that uses the hyperbolic tangent sigmoid transfer function in all layers and trains its neurons with the back propagation training algorithm. It is known as Multi-Layer Perceptron (MLP). This network has an input layer, two hidden layers and an output layer. Each row contains the minimum and maximum value that a particular input node can have. The equation for output in a MLP with one hidden layer is given as [8]:

$$O_x = \sum_{i=1}^{N} \beta_i \; g(w_i \; x + b_i) \qquad (1)$$

where βi is the bias value and wi weight value between the it hidden neuron. The process of adjusting the weights and biases of the MLP is known as training. Training the MLP is done in two broad passes - one a forward pass and the other a backward calculation with error determination and connecting weight updating in between. The output from the hidden layer is obtained depending upon the choice of the activation function. The values of the hidden nodes are :

$$net_{mj}^{h} = \sum_{i=1}^{L} w_{ji}^{h} p^{mi} + \phi_j^{h} \qquad (2)$$

The values of the of output node can be obtained as :

$$o_{mk}^{\;o} = f_k^o\left(net_{mj}^{h}\right) \qquad (3)$$

Forward Computation: The errors can be computed as :

$$e_{jn} = d_{jn} - o_{jn} \qquad (4)$$

The mean square error (MSE) is calculated as :

$$MSE = \frac{\sum_{j=1}^{M} \sum_{n=1}^{L} e^2_{jn}}{2M} \qquad (5)$$

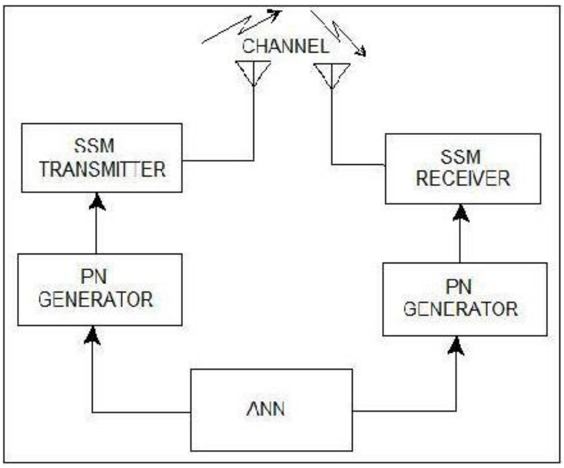

Figure 3 : System Model

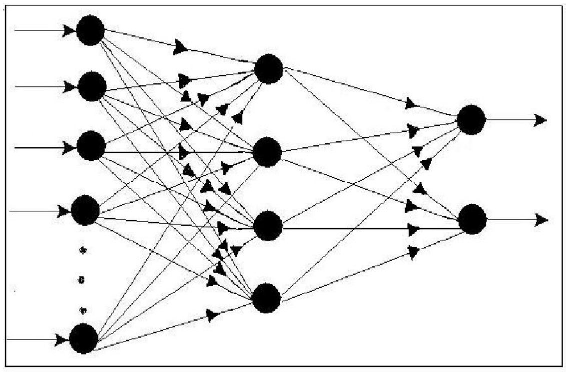

Figure 4 : Multi-layer Perceptron

Error terms for the output layer are :

$$\delta_{mk}^{o} = O_{mk}^{o}(1 - O_{mk}^{o})e_{mn} \qquad (6)$$

Error terms for the hidden layer :

$$\delta_{mk}^{o} = O_{mk}^{o}(1 - O_{mk}^{o}) \sum \delta_{mj}^{o} \; w_{jk}^{o} \qquad (7)$$

Weight Update: Between the output and hidden layers :

$$w_{kj}^{o}(t+1) = w_{kj}^{o}(t) + \eta \delta_{mk}^{o} \, o_{mj} \qquad (8)$$

where η is the learning rate. One cycle through the complete training set forms one epoch. The above is repeated till MSE meets the performance criteria. This cycle constitutes the learning phase of the MLP [8].

B. *Training*

ANNs can often generalize and correctly classify inputs unknown to them previously. A training set is used to update network weights and biases, and after training, each network goes through a testing procedure to gather data for evaluation of its usefulness. A diagram of Multi-Layer Perceptron (MLP) is shown in Fig. 4.

TABLE I. NETWORK PARAMETERS

Sl No	Item	Description
1	Network type	MLP
2	Hidden layers	2
3	Hidden layer size	10
4	Transfer function	Tangential sigmoidal
5	Performance fuction	LMSE
6	Training algorithm	Back Propagation

C. *Testing*

One set of data is obtained in order to test each network. This set of data consists of data bits whose length is equal to the PN sequence and is presented to each ANN. Network specific procedures are then used to compare the output of each ANN against the desired outputs. The training time is a parameter that is independent of the test data and is the number of seconds spent training a particular network.

D. *Evaluation*

Running an ANN simulation in MATLAB produces a matrix of outputs. These values can be compared to a target matrix of desired ANN outputs to evaluate the performance of each network. The input layer consists of a few number of nodes equal to the length of the PN sequence. The output layer has a size equal to the number of bits to be included in the ANN generated PN sequence. The performance function is the least mean of squared error (LMSE) which minimizes the average of the squared network errors. Once all the inputs have been presented, the training algorithm modifies the weights according to its procedure. The training of the ANN is carried out using four different training methods. The total number of epochs for each ANN is around 5000. These are

- Backpropagation with gradient descent (BPGD).
- Backpropagation with gradient descent and momentum (BPGDM).
- Backpropagation with gradient descent and adaptive learning rate (BPGDA).
- Backpropagation with gradient descent, momentum and adaptive learning rate (BPGDX).

Out of these four training methods, BPGD turns out to be most efficient in terms of training time, accuracy and number of epochs required to reach the desired goal.

E. *System Design*

With reference to Fig. 3 the PN sequence used in the analysis of the DSSSM system has the parameters as shown in Table II. In both DS and FH systems a 32 bit binary stream is taken as the message signal. The data in this signal can take two amplitudes, where one amplitude can take two amplitudes, where one amplitude corresponds to logical 1 and the other amplitude to logical 0.

TABLE II. PARAMETERS OF THE PN SEQUENCE FOR THE DSSSM

Sl no	Item	Description
1	Chip rate (*rc*)	8 KHz
2	Chip time (*Tc*)	0.0125 µs
3	Sequence length (N)	31bits
4	Code period (N*Tc*)	0.3875 µs

This data stream is multiplied with a cosine function of a higher frequency. In fact, this modulation can be considered as the primary modulation. Mathematically,

$$s(t) = 1 \text{ or } s(t) = -1$$

such that the premodulated signal m(t) is given as $m(t) = s(t)\cos(2\pi ft)$ where $f = f1$ and $f = f2$ are the two frequencies for s(t) = 1 and s(t) = -1 respectively taken such that these frequencies lie within the spread spectrum bandwidth.

For simplicity, it has been assumed that all amplitudes are equal to one. After the primary modulation, the signal is modulated again, to spread its frequency spectrum. This modulation is the multiplication of the signal m(t) with a digital signal of larger frequency range. The transmitted spread spectrum signal is given by

$$x(t) = m(t)c(t)$$

where c(t) is the PN sequence.

At the transmitter, binary symbols are transmitted with energy E per symbol. The noise n(t) added to this transmitted signal has an effect only on the amplitude. It depends on the signal-to-noise ratio (SNR). Hence the signal transmitted through the channel can be represented by the equation

$$y(t) = x(t) + n(t)$$

To recreate data at the receiver, the signal is despreaded first and then normally demodulated. The despreading can only be successful if the code sequence generated in the receiver is exactly synchronised with that of the received signal.

The parameters of the PN sequence used for the analysis of the FHSSM system are given in Table III. With each of the signal sets considered, a unique PN sequence is generated by the ANN. There is a one-to-one correspondence between the signal to be transmitted and the PN sequence generated. This correspondence is used at the receiver for recovery of the data. The ANN for a given input of received signal provides the unique PN code. The precision of the PN code can be varied with better ANN configuration and training. The entire system is trained and tested in a setup closely related to an environment where the SSM operates.

The performance of the spread spectrum system in presence of partial band noise jammer is analysed for different fractions of the spread spectrum bandwidth. A jammer is considered that transmits noise over a fraction of the total spread spectrum bandwidth. The jammer signal is a Gaussian noise with a flat power spectral density over the jammed bandwidth. The jammer spreads noise of the total.

TABLE III. PARAMETERS OF THE PN SEQUENCE FOR THE FHSSM

Sl no	Item	Description
1	Chip rate (*rc*)	250 Hz
2	Chip time (*Tc*)	0.0040 µs
3	Sequence length (N)	31bits

4	Code period (N*Tc*)	0.124 µs

power J over some frequency range of bandwidth Wj, which is a subset of the total spread spectrum bandwidth Wss.

It is assumed that the shifts in the jammed band coincide with carrier hop transitions. It is experimentally found that when the fraction of the jamming bandwidth is decreased, the probability of the system being jammed is decreased but the jammed signals suffer a higher error rate, resulting in degradation in the performance of the system and vice-versa. The error rate is also calculated by varying the number of hops per data symbol.

III. HAMMING AND CRC CODING

Hamming code is a linear error-correcting code which can detect up to two simultaneous bit errors, and correct single bit errors. Thus reliable communication is possible when the Hamming distance between the transmitted and received bit patterns is less than or equal to one. By contrast, the simple parity code cannot correct errors, and can only detect an odd number of errors [9]. A cyclic redundancy check (CRC) is an error-detecting code designed to detect accidental changes to raw data, based on the theory of cyclic error-correcting codes. CRCs are so called because the check (data verification) code is a redundancy (it adds zero information to the message) and the algorithm is based on cyclic codes [9].

IV. RESULTS AND DISCUSSION

Based on the data generated by simulation of DSSSM and FHSSM systems, relationship using DPSK modulation technique between BER as a function of the jamming factor and number of hops is obtained. Table IV shows that for the DSSSM system with the increase in the jamming factor from 0.1 to 1.0, the BER decreases from 0.0366 to 0.0216 for the PN sequence generated using shift registers while the BER decreases from 0.0307 to 0.0186 for the PN sequence generated using ANNs. Table V shows that in case of the FHSSM system, keeping the hop rate at 2 hops/symbol, as the jamming factor is increased from 0.1 to 1.0, BER of 0.0295 and 0.0233 respectively is generated using the PN sequence generated using shift registers while the BER is 0.0286 and 0.0223 in case of the PN sequence generated using ANNs. Tables VI–VII show the results for both Hamming and CRC coded information sequences. Table VI shows that in case of the DSSSM system as the jamming factor is increased from 0.1 to 1.0, the BER goes down from 0.0265 to 0.0169 for the PN sequence generated using shift registers in case of the Hamming coded sequence. The corresponding BER is 0.0240 at jamming factor 0.1 and BER For Different Values Of The J amming Factor Of The DSSSM.

Sl. No.	**BER for different values of the jamming factor of DSSSM system**		
	Jamming factor	***BER (without ANN)***	***BER (with ANN)***
1	0.1	0.0366	0.0307
2	0.4	0.0316	0.0271
3	0.5	0.0299	0.0237
4	0.7	0.0280	0.0225
5	0.8	0.0266	0.0202
6	1.0	0.0216	0.0186

TABLE IV. BER FOR DIFFERENT VALUES OF THE JAMMING FACTOR OF THE FHSSM AT 2 HOPS/SYMBOL

Sl. No.	**BER for different values of the jamming factor of FHSSM system**		
	Jamming factor	***BER (without ANN)***	***BER (with ANN)***
1	0.1	0.0295	0.0286
2	0.5	0.0288	0.0251
3	0.6	0.0274	0.0248
4	0.8	0.0255	0.0240
5	1.0	0.0233	0.0223

TABLE V. BER FOR DIFFERENT VALUES OF THE JAMMING FACTOR OF THE DSSSM SYSTEM FOR HAMMING AND CRC CODED INFORMATION SEQUENCES

BER for different values of the jamming factor of DSSSM system				
Jammi ng factor	***BER (without ANN for Hammi ng coding)***	***BER (with ANN for Hammi ng coding)***	***BER (witho ut ANN for CRC coding)***	***BER (with ANN for CRC codin g)***
0.1	0.0265	0.0240	0.0299	1x10^{-4}
0.4	0.0249	0.0234	0.0249	1x10^{-4}
0.5	0.0218	0.0207	0.0233	1x10^{-4}
0.7	0.0187	0.0181	0.0216	1x10^{-4}

BER for different values of the jamming factor of DSSSM system				
Jamming factor	***BER (without ANN for Hamming coding)***	***BER (with ANN for Hamming coding)***	***BER (without ANN for CRC coding)***	***BER (with ANN for CRC coding)***
0.8	0.0187	0.0181	0.0183	$1x10^{-4}$
1.0	0.0169	0.0156	0.0183	$1x10^{-4}$

0.0156 at jamming factor of 1 for the PN sequence generated using ANNs for the Hamming coded sequence.

TABLE VI. BER FOR DIFFERENT HOPS OF THE PN SEQUENCE OF THE FHSSM SYSTEM FOR HAMMING AND CRC CODED INFORMATION SEQUENCES

BER for different hops of the PN sequence of FHSSM system				
Number of hops	***BER (without ANN for Hamming coding)***	***BER (with ANN for Hamming coding)***	***BER (without ANN for CRC coding)***	***BER (with ANN for CRC coding)***
2 hops/symbol	0.0251	0.0242	0.0251	0.0242
10 hops/symbol	0.0246	0.0240	0.0246	0.0240

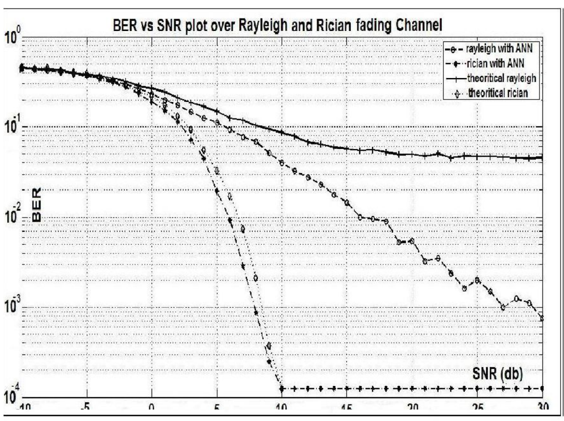

Figure 5: BER vs SNR plot in Rayleigh and Rician fading channels over SNR range -10 ≤ SNR ≤ 30dB.

The BER is 0.0299 at jamming factor 0.1 and 0.0183 at jamming factor of 1 for the PN sequence generated using shift registers in case of the CRC coded sequence. The BER is $1x10^{-4}$ at jamming factor 0.1 and $1x10^{-4}$ at jamming factor of 1 for the CRC coded sequence in case of the PN sequence generated using ANNs. Table VII shows that in case of the FHSSM system using the PN sequence generated using shift registers, as the number of hops is increased from 2 hops/ symbol to 10 hops/symbol, the BER is decreased from 0.0251 to 0.0246 respectively and the BER is decreased from 0.0242 to 0.0240 respectively for the PN sequence generated using ANNs for both the Hamming coded sequence and the CRC coded sequence.

From the above tables it is seen that the use of the PN sequence generated using ANNs in the spread spectrum system results in a better error performance than the one using the PN sequence generated using shift registers. Further it is seen that when the information sequence is coded using Hamming and CRC coding the BER has

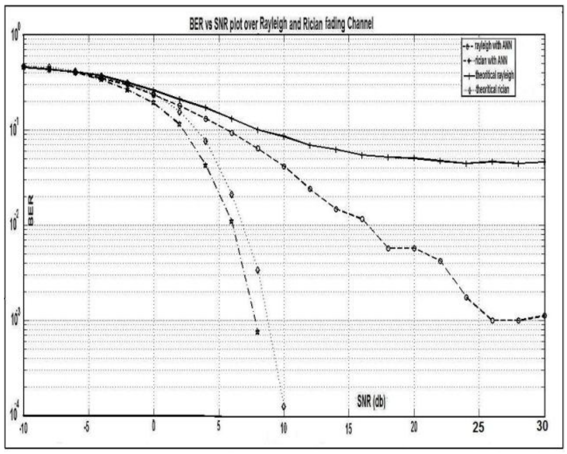

Figure 6 : BER vs SNR plot in Rayleigh and Rician fading channels over SNR range -10 ≤ SNR ≤ 30dB using Hamming coding.

reduced though the use of coding bits leads to some waste in bandwidth. With the increase in the number of hops, the error rate is decreased and vice-versa. Also as the jamming factor is decreased, the probability that the system is jammed is decreased but the jammed signals suffer a higher error rate resulting in degradation in the performance of the system. Fig. 5 shows the bit error rate (BER) in case of the ANN-assisted spread spectrum system and the one without using ANNs in Rayleigh and Rician fading channels for different values of signal-to-noise ratio (SNR). Again Figs. 6 and 7 show the bit error rate (BER) in case of the ANN-assisted spread spectrum system and the one without using ANNs in Rayleigh and Rician fading channels for different values of signal-to-noise ratio (SNR) for Hamming and CRC coded information sequences. Fig. 6 shows the comparison of BER with Hamming coding over the SNR range -

10dB to 30 dB. Similarly Fig. 7 shows that the BER with CRC coding has fallen to $4x10^{-4}$ and 10^{-4} in Rayleigh fading channel without ANN and Rayleigh fading channel with ANN respectively over the SNR range -10dB to 30 dB. It represents 13% and 14% of improvement compared to uncoded forms. Thus the use of ANN-assisted PN sequence generation and coding is justified for application in DS/FH SSM in wireless channels.

V. CONCLUSION

The work shows the effectiveness of the use of ANN for PN sequence generator and coding for both DS and FH SSM systems. The extracted results show that the ANN-assisted PN sequence generator helps in providing superior BER values in both Gaussian and Multipath faded channels. The work also demonstrates that performance improves further

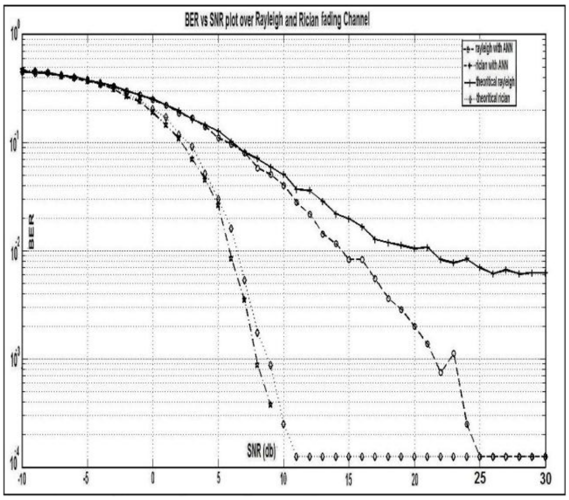

Figure 7 : BER vs SNR plot in Rayleigh and Rician fading channels over SNR range -10 ≤ SNR ≤ 30dB using CRC coding.

with the use of coding. The combination proves to be effective in wireless channels. The ANN-assisted PN sequence is robust enough to prevent false triggering which also helps it to provide better performance in wireless channels. Thus, the system proposed can prove to be effective and enhance performance of DS/FH SSM transmission.

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