Analysis and Reduction of Multi Co-channel Interference in Wireless Communication Systems

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ABSTRACT

The goal of this research is to analyze the effect of multi co-channel interference (CCI) on direct sequence (DS) spread spectrum signals used in wireless networks and analyze the bit error rate (BER) of modulated signal received in presence of multi co-channel interfering signals and additive white Gaussian noise and multiple paths. Radial Basis Function (RBF) neural network was used to reduce the multi CCI impact.

Simulation showed that the RBF neural network has adapted to the relationship between the interfered input signals and target signal, where after few epochs the BER could be reduced to less than 10^{-2} for the cases of one and two CCI in the range 14-16dB of E_b/N_0. But for the case of three CCI the BER has reduced to less than 10^{-3} in the range 15-16dB of E_b/N_0.

Key Words: Co-channel interference -Wireless communication systems.

INTRODUCTION

With the expected increase in overcrowding of frequency spectrum by the use of satellites, mobile and local wireless networks, in conjunction with frequency reuse mitigation techniques in order to allow usage of higher bands, the effect of different types of interference is likely to increase in the future [Smadi *et al*., 2009].

Co-channel cells are those cells using the same frequency channels in different clusters of cellular system and the interference between signals from these cells is called co-channel Interference (CCI). The CCI is considered the most affective type of interference, therefore studying its reduction in cellular networks of great importance. Different equalization techniques have been used to mitigate the residual CCI impact such as power control, soft handoff and adaptive filters [Stavroulakis, 2003].

Related work: The problem of detecting BPSK signal in the presence of one interferer and noise has been introduced by several papers. Guha *et al*. (2009) proposed a RBF based equalizer which is trained using Wilcoxon learning method. The equalizer presented shows considerable performance gain for signals corrupted by burst noise. Flattie (2012) varied the load factor and antenna tilt to reduce the Co-channel interference for GSM (Global System for Mobile) network, the variability of different interference with the cellular system parameters has been investigated. CCI ≥ 12 dB can be increased by 3% when changing mechanical tilt by 4 degree. Danyang *et al.* (2013) applied a novel adaptive filtering strategy based on dynamic selection of frequency subbands in Wireless Sensor Network (WSN), the simulating results based on NS2 (Network Simulator version 2) indicated that the system BER can be improved by 5dB at most. Geevarghese *et al.* (2013) showed the effects of pre-processing in bit error rate of neural network interference cancellation in spread spectrum receivers. Feed-Forward Neural Networks with back propagation was used for interference cancellers. The works shows that pre-processing can bring adequate improvement in bit error rate as well as complexity, but still the complexity and the intensive calculations of back propagation neural network are the major limiting factor of applying this method.

The new work in this manuscript can be summarized as follows: the modeling and numerical results presented demonstrate the system performance under very realistic propagation and detection conditions including CCI and AWGN; the use of Radial Basis Function (RBF) neural network algorithm to mitigate the negative effects of CCI not only burst noise as in [Guha *et al.*, 2009], CCI reduction analysis of up to three CCI, while in literature one or two CCI are usually analyzed. Also were driven closed-form bit-error probability expressions for spread-spectrum systems by approximating narrowband interferers as independent asynchronous tone interferers.

MATERIALS AND METHODS

The research method can be summarized in the following steps:

- Mathematical analysis for DS spread spectrum signal with binary phase shift keying (BPSK) modulation and with multi co-channel interferers, and then derive the probability of error.
- Define co-channel interference power gain at which BER of the desired signal equal to zero.
- Analyze the effect of multi co-channel interfering signals (1 to 3 CCI) and multipath fading in presence of additive white Gaussian noise on BPSK modulated signal using orthogonal Walsh codes for CCI suppression.
- Apply equalization methods to mitigate the residual CCI impact.

In DS spread spectrum systems the information channel bandwidth is expanded by shifting the phase of the carrier pseudo-randomly several times per second according to PN generator pattern [Stavroulakis, 2003]. If the information baseband signal of the form:

$$v(t) = \sum_{n=-\infty}^{\infty} V_n g(t - nT_b) \qquad (1)$$

Where $V_n = \pm 1$; g(t) is a binary sequence of duration T_b (a rate R=1/T_b Hz)
The sequence from PN generator will take the form:

$$c(t) = \sum_{n=-\infty}^{\infty} C_n p(t - nT_c) \qquad (2)$$

Where $C_n = \pm 1$; p (t) is a rectangular sequence of duration T_c (a rate 1/T_c Hz)

The information baseband signal v (t) is used to modulate a carrier signal:

$$u(t) = U_c \cos(2\pi f_c t) \qquad (3)$$

The resulting modulated signal is a binary phase shift keying (BPSK) signal, which is multiplied with PN generator sequence c (t). The resulting spreading signal with a rate 1/T_c and can be written as following:

$$u(t) = U_c v(t) c(t) \cos[\omega_c t + \theta(t)] \qquad (4)$$

Where:

$$\theta(t) = 0 \quad for \quad v(t)c(t) = +1$$

$$\theta(t) = \pi \quad for \quad v(t)c(t) = -1$$

The 1/T_c is called the chip rate, which equal to the bandwidth of the transmitted signal (W) [Tsang *et al.,* 2004].

At the receiver the information is decoded (de-spreaded) by multiplying the modulated signal (4) with a replica of PN code sequence generated in the receiver and then demodulated. The resulting signal can be written as follows:

$$u(t) = U_c v(t) c^2(t) \cos[\omega_c t + \theta(t)] \qquad (5)$$

Since c^2 (t) =1 for all t. Equation (5) can be rewritten as:

$$u(t) = U_c v(t) \cos[\omega_c t + \theta(t)] = U_c v(t) \cos(2\pi f_c t) \qquad (6)$$

The bandwidth of the resulting signal in equation (6) is approximately R=1/T_b Hz, which is the bandwidth of the original information signal.

From equation (6), DS spread spectrum signal is affected only by interference, which falls within the bandwidth of the information signal R. In this case, we can add the interference to the received signal in equation (4):

$$u(t) = U_c v(t) c(t) \cos(2\pi f_c t) + i(t) \qquad (7)$$

After dispreading we get:

$$u(t)c(t) = U_c v(t)\cos(2\pi f_c t) + i(t)c(t) \qquad (8)$$

Suppose that the multi co-channel interference signal has sinusoidal form:

$$i(t) = \sum_{i=1}^{N} V_i \sin(2\pi f_i t) \qquad (9)$$

Where f_i the frequencies of N interfering signals within the bandwidth of a binary phase shift keying signal u(t).

Multiplying the interference i(t) with PN generator sequence c(t) will spread it to spread spectrum signal bandwidth (W) with power spectral density:

$$P_d = \sum_{i=1}^{N} \frac{P_i}{W} \qquad (10)$$

Where P_i is the average power of the N interfering signals. Demodulation the received signal using a demodulator with a bandwidth R will produce interference within the demodulated signal with a power:

$$P_d R = \sum_{i=1}^{N} \frac{P_i}{W} R = \sum_{i=1}^{N} \frac{P_i}{P_g} \qquad (11)$$

Where P_g=W/R is the processing gain of DS system, what means the reduction of co-channel interference with a ratio of P_g**.**

The probability of error in DS system with is a binary phase shift keying modulated signal is identical to un-spread BPSK [Stavroulakis, 2003]:

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \qquad (12)$$

E_b –signal energy per bit

N_0- noise power density per Hz

The Q-function is the tail probability of the standard normal distribution:

$$Q(z) = \int_z^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx$$

If the multi co-channel interference has power spectral density as in equation (10), the approximate probability of error is:

$$P_e = Q\left(\sqrt{\frac{2E_b}{N_0 + \sum_{i=1}^{N} \frac{P_i}{W_i}}}\right) \qquad (13)$$

Spreading consists of multiplying the input data by a pseudo-random or pseudo-noise (PN) sequence of length 64bits, this sequence bit rate which is much higher than the data bit rate increases the data rate and adds redundancy to the system. The ratio of the sequence bit rate to the data rate is known as the spreading factor. When the signal is received, the spreading is removed from the desired signal by multiplying it by the same PN sequence that is exactly synchronized to the transmitted PN signal. When such a de-spreading operation is applied to the co channel interference, ideally there is no further contribution to the user of interest's signal level. This can be achieved in CDMA systems by assigning each user/transmitter distinct code that has low cross-correlation properties over the other spreading sequences such as Walsh codes [Tsang *et al.*, 2004, Stavroulakis, 2003].

System Model:

The simulation setup in figure (1) uses random binary data from Bernoulli source which is BPSK modulated, spreaded by orthogonal codes of length 64 and then transmitted over an additive white Gaussian noise (AWGN) channel, where noise and co-channel interference are added.

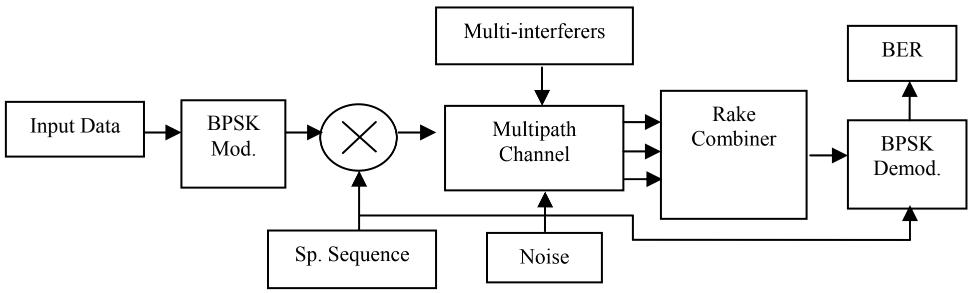

Figure (1): Simulation setup

The signal is transmitted over multiple paths. The receiver consists of a de-spreader followed by a BPSK demodulator; the receiver employs a Rake combiner which combines the independent received paths. For the same data and the same channel settings, the simulation setup calculates the performance for one or multi-user transmission. The error display shows the number of error bits after comparing the original bits with the detected ones. Simulations were conducted using MATLAB program. The following results show the performance of different sequences on co-channel interference suppression

RESULTS AND DISCUSSION

For a single-user interfered with a one co-channel user with two data inputs being independently spread by different orthogonal codes with BPSK modulation and three multiple paths, the following results were obtained. For user1 delays 0;2;6 samples and for co-channel user paths delays 0;3;6 samples. As shown in figure (2) for a single user without CCI optimum reception can be achieved for E_b/N_0 value not less than 8dB, while this value for a user with CCI around 12dB.

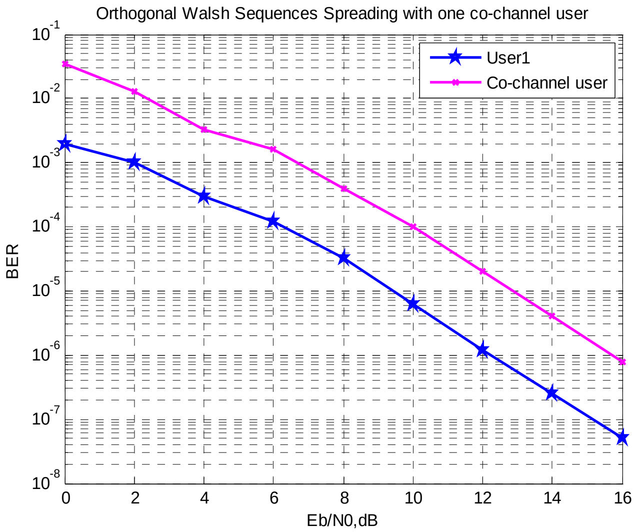

Figure (2): Number of paths 3 User1 delays 0; 2; 6 samples and co-channel user paths delays 0; 3; 6 samples

To analyze the effect of co-channel interferer's gain on the desired user, a simulation was made using Walsh codes with three multiple paths for two users. Figure (3) shows the relation of BER versus E_b/N_0 for the desired user for different values of co-channel interferer's power gain (-6,-8dB), these values were chosen to make the effect of interference very clear. The results show that the BER of the desired user is decreasing by decreasing the interferer's gain (the best result is BER = 4.3×10^{-6} at E_b/N_0 = 8dB for interferer's gain= -8dB, i.e. for $E_b/N_0 \geq$ 8dB the effect of co-channel interferer aims to minimum value).

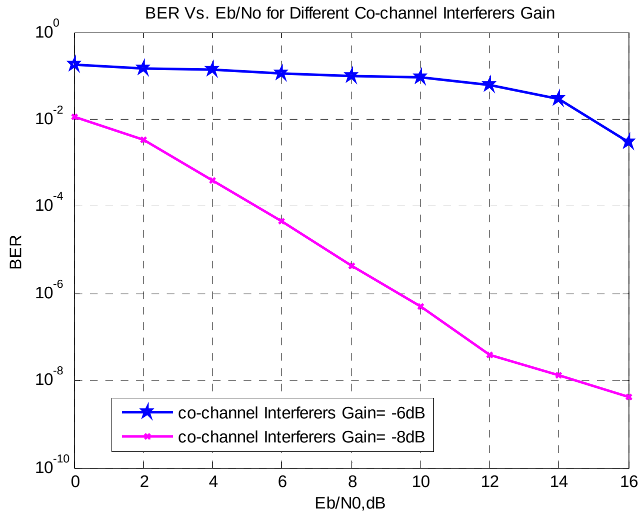

Figure (3): BER vs. Eb / N0 of the desired user for different values of Co-channel interferer's power gain (-6,-8dB)

For a single-user interfered with one CCI with two data inputs being independently spreaded by different orthogonal Walsh codes with BPSK modulation and three multiple paths. Paths delays for the desired user are 0;2;6 samples and for co-channel interferer are 0;3;6 samples and interferer's gain -6dB. Figure (4) shows that the BER of the desired user is less than 10^{-2}.

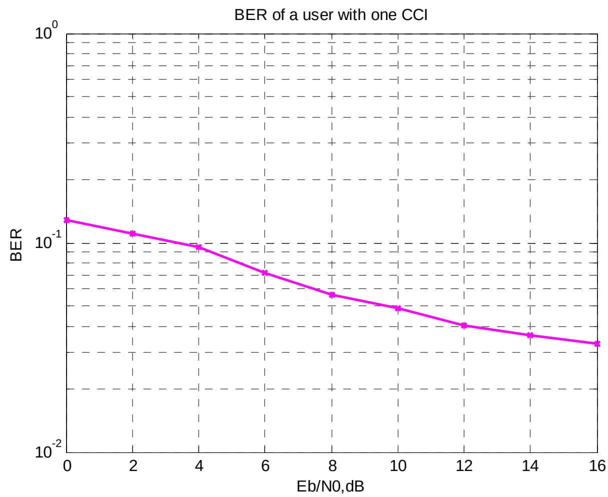

Figure (4): Number of paths 3 User1 with paths delays 0; 2; 6 samples, co-channel user with paths delays 0; 3; 6 samples and interferer's gain -6dB

For a single-user interfered with two CCI with data inputs being independently spreaded by different orthogonal codes with BPSK modulation and three multiple paths. Paths delays for the desired user are 0;2;6 samples and for co-channel interferers are 0;3;6 samples. As shown in figure (5) the BER of the desired user has increased comparing with the case of one CCI in figure (2).

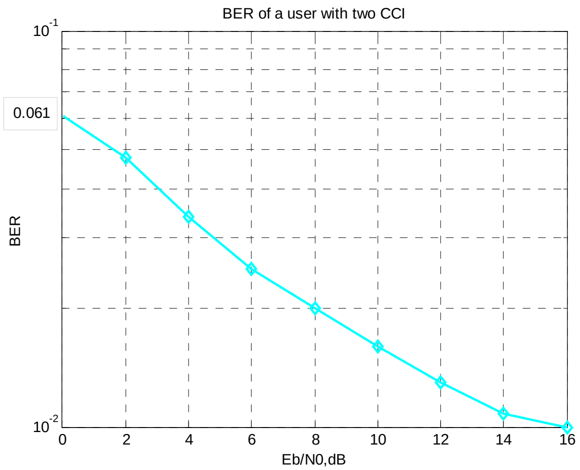

Figure (5): A single user interfered with two co-channel interferers

For a single-user interfered with three CCI with data inputs being independently spreaded by different orthogonal codes with BPSK modulation and three multiple paths the following results were obtained. Paths delays for the desired user are 0;2;6 samples and for CCI are 0;3;6 samples. From figure (6) we conclude that as the number of CCI increases the BER of the desired user increases, but its curve changes in the range 0.252 -0.225. What means adding more CCI to the system will not considerably effect on the BER of the desired user.

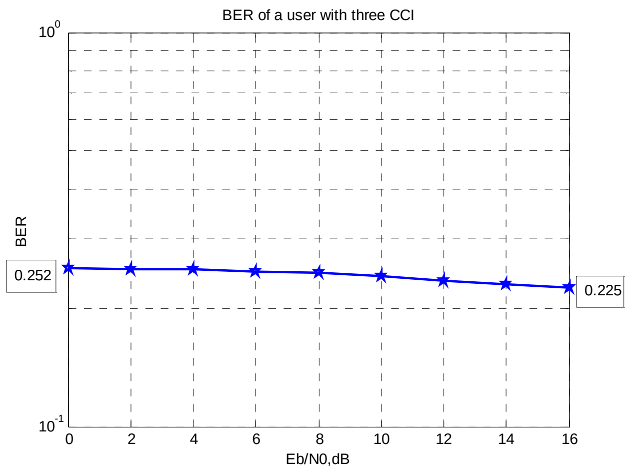

Figure (6): A single user interfered with three co-channel interferers

Reduction of CCI:

To reduce the CCI impact an adaptive algorithm using a radial basis approximation neural network was used before the detection process for function approximation problems. Radial basis networks (RBF) networks are specially recommended for surface with regular peaks and valleys since efficient and accurate design can be obtained, while for surfaces without regular peaks and valleys traditional neural networks are preferred as a general model [Xie *et al.*, 2011].

RBF is a network with two layers, a hidden layer of radial basis neurons and an output layer of linear neurons. The weights and biases of each neuron in the hidden layer define the position and width of a radial basis function. Each linear output neuron forms a weighted sum of these radial basis functions. With the correct weight and bias values for each layer, and enough hidden neurons, a radial basis network can fit any function with a desired accuracy.

The network uses the NEWRB function to create a radial basis network that approximates a function defined by a set of data points. The function NEWRB quickly creates a radial basis network which approximates the function defined by input vector (x) and target vector (t). In addition to the input vector used as training set and targets, NEWRB takes two arguments, the sum-squared error goal (`eg`) and the spread constant (`spc`). The Radial basis neural network architecture is shown in figure (7).

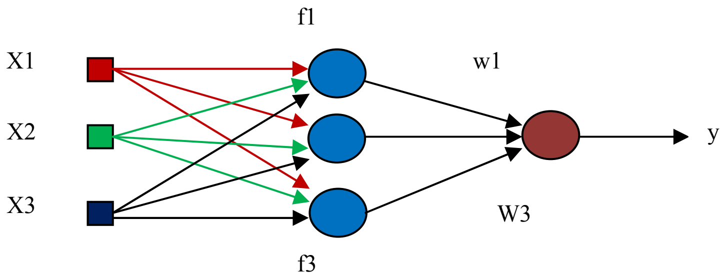

Figure (7) Radial basis neural network architecture

The output of radial basis function (RBF) depends on the distance of the input vector from a given stored vector, where one hidden layer uses neurons with RBF activation functions f describing local receptors:

$$f_1; f_2; f_3$$

$$f_{\mathrm{spc}}(net) = \sqrt{(net^2 + spc^2)}$$

$$spc > 0$$

Where;

$$net = \| x - t \|$$

- x: is the input vector.
- t: is the stored vector and is called the center.
- $\| x - t \|$ distance of (x) from vector (t)
- spc: is called spread.

Then one output node is used to combine linearly the outputs of the hidden neurons:

$$y = \sum_{i}^{3} w_i f_i(\| x_i - t_i \|) = w_1 f_1(\| x_1 - t_1 \|) + w_2 f_2(\| x_2 - t_2 \|) + w_3 f_3(\| x_3 - t_3 \|)$$

The input vector gives a contribution that depends on its weight (w) and on its distance from the stored vector (t). The network is working according to the following algorithm:

1. NEWRB function creates a two-layer network, and then the network is simulated. Initially the hidden layer has no neurons NEWRB function adds neurons to this layer until it meets the specified mean squared error goal.
2. The weights and biases of each neuron in the hidden layer define the position and width of a radial basis function. Each linear output neuron

forms a weighted sum of these radial basis functions. With the correct weight and bias values for each layer, and enough hidden neurons, a radial basis network can fit any function with any desired accuracy.

3. The input vector with the greatest error is found.
4. A neuron is added with weights equal to that vector.
5. The pure line layer weights are redesigned to minimize error.

Thus, the neural network simulates an adaptive network; it takes an interfered signal and a target signal (without CCI) and filters the interfered signal adaptively. The following parameters were chosen for the network:

- sum-squared error goal equal to zero(`eg=0`);
- spread of radial basis functions constant equal to one(`spc=1`),

Data sequence without CCI is used as a target signal, and the layer adapts to it. Initially because at the first call to adapt, the default input conditions are used, then the hidden layer continues to adapt for a new sequence using the previous final input conditions as initial conditions, and train the newly initialized layer on the entire sequence to an error goal of 0.

Figure(8) shows after few epochs the network has learned the relationship between the input with one CCI and the target signals and the error drops to less than 10^{-2} at E_b/N_0 =14dB with good approximation of neural network.

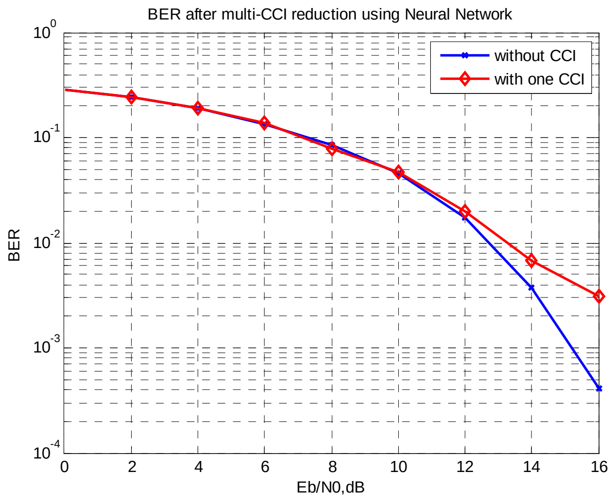

Figure (8): The relationship between inputs with one CCI and the target signals

Figure (9) shows that after few epochs the network has learned the relationship between the input with two CCI and the target signals and the error drops to less than 10^{-2} at E_b/N_0 = 14dB with better approximation of neural network than the case of one CCI, what means that the two CCI compensate each other and the result is less effective on the user data.

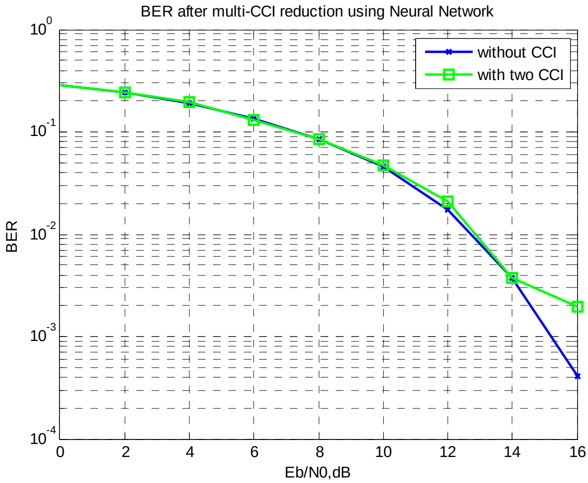

Figure (9): The relationship between inputs with two CCI and the target signals

Figure (10) shows that after few epochs the network has learned the relationship between the input with three CCI and the target signals with the best approximation of neural network than the case of one or two CCI for all values of E_b/N_0.

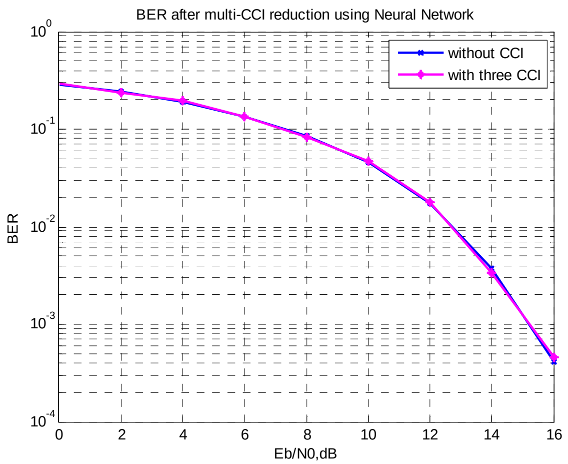

Figure (10): The relationship between inputs with three CCI and the target signals

Figure (11) shows the BER performance of user data after multi-CCI reduction using RBF neural network. From this figure, we conclude that the network has reduced the BER to less than 10^{-2} for the cases of one and two CCI in the range 14-16dB of E_b/N_0. But for the case of three CCI the BER has reduced to less than 10^{-3} in the range 15-16dB of E_b/N_0. What means the best value of BER is less than10^{-3} in the range 15-16dB of E_b/N_0 in case of reception signals interfered with multi-CCI.

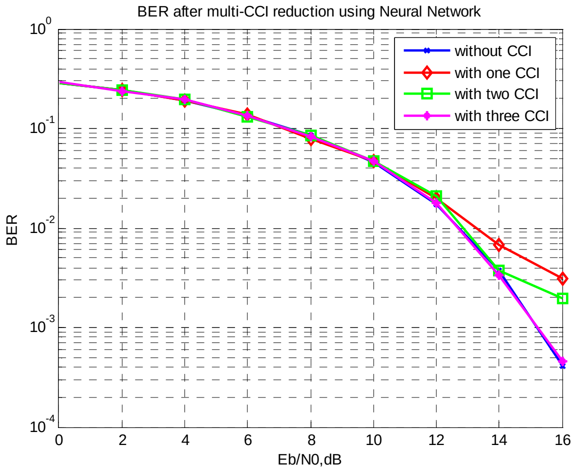

Figure (11): BER performance after multi-CCI reduction using neural network

CONCLUSIONS

The following can be concluded from the this study:

1. Bit error rate of BPSK modulated signal detection in presence of co-channel interfering signal, additive white Gaussian noise and multiple paths was analyzed. The effect of co-channel interference gain variation on the received signal was studied.
2. To minimize the effect of multi co-channel interference adaptive equalization algorithms can be used or optimization methods using a radial basis approximation neural networks and MSE (Minimum Square Error) algorithm.
3. Simulation showed that the neural network has adapted to the relationship between the interfered input signals and the target signal, where after few epochs the BER could be reduced to less than 10^{-2} in the range 14-16dB of E_b/N_0 for the case of one and two CCI.
4. For the worst case of three CCI the BER has reduced to less than 10^{-3} in the range 15-16dB of E_b/N_0.

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تحليل و تخفيض تداخل القناة المتعدد في نظم الاتصالات اللاسلكية

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الملخص

يهدف البحث إلى تحليل تأثير تداخل القناة المتعدد على إشارات الطيف المنتشر ذات التتابع المباشر المستخدمة في الشبكات اللاسلكية وتحليل معدل خطأ الخانة لإشارة التعديل المستقبلة بوجود إشارات تداخل قناة متعددة وضجيج غاوس الأبيض المضاف والمسارات المتعددة. تم استخدام الشبكة العصبونية نوع تابع الشعاع الأساسي لتقليل تأثير تداخل القناة المتعدد.

بينت المحاكاة أن شبكة تابع الشعاع الأساسي ولَفت على العلاقة بين إشارات الدخل المتداخلة والإشارة المرغوبة، حيث وبعد عدة تكرارات تم تخفيض معدل خطأ الخانة لأقل من 10^{-2} من أجل حالات تداخل القناة 1 و 2 ضمن المجال dB16-14 للنسبة Eb/N0. بالنسبة للحالة الأسوأ بثلاثة متداخلين فينخفض معدل خطأ الخانة لأقل من 10^{-3} ضمن المجال dB16-15 للنسبة Eb/N0 .

الكلمات المفتاحية: تداخل القناة، شبكات الاتصالات اللاسلكية.