ISSN: 2456 – 3080
International Journal of Applied and Advanced Scientific Research
Impact Factor 5.255, Special Issue, July - 2017
6th International Conference on Innovations in Electronics & Communication Engineering
On 21st & 22nd July 2017 Organized By
Department of ECE, Guru Nanak Institutions, Hyderabad, Telangana

GAME THEORETIC APPROACH FOR MULTIUSER DETECTION AND POWER CONTROL FOR CDMA SYSTEMS

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Cite This Article: R. Nirmala Devi & K. Kishan Rao, "Game Theoretic Approach for Multiuser Detection and Power Control for CDMA Systems", International Journal of Applied and Advanced Scientific Research, Special Issue, July, Page Number 27-34, 2017

Abstract:

Increasing demand of real-time multimedia communication motivates to develop an efficient system to provide better quality of service for end user. Recently, cellular communication system has grown drastically and still increasing. For this type of communication systems, CDMA (Code-Division Multiple Access) technique is considered as most promising as satisfying technique to meet the end-user requirement for real-time communication. However, during communication, original signal gets affected or contaminated due to channel interference or near-far effect in CDMA system which can degrade communication performance. This issue can be addressed by using multiuser detection techniques. However, various techniques have been introduced but still it remains a challenging task due to computational complexity. Similarly, power consumption during communication is also a challenging task in these researches. In this work, multiuser user detection and power controlling issues of CDMA systems are addressed using Game theoretic approach using non-cooperative game theory. Proposed approach aims on the maximization of utility functions by considering more number of users in the network. Proposed technique obtains relationship between utility maximization and data sequence vector which helps to find an optimal solution. Furthermore, technique uses Nash Equilibrium scenario for iterative power adjustment using multiuser system efficiency. An extensive simulation study is carried out which shows that proposed approach can be used for multiuser detection and power control strategy in CDMA systems.

1. Introduction:

Demand of real-time communication is growing drastically which includes real-time communication such as voice, multimedia communication etc. This increasing demand of multimedia communication claims for higher rate of data transmission and robust channels conditions. In this field of multimedia communication, CDMA systems are considered as promising technique for multiuser communication scenario. Since CDMA based communication systems are widely used for multi-user communication scenario where all users operate in the same communication medium where assigned frequency and time also remains same for each user. During communication, spreading codes are used for transmitting the information over communication channel. In order to perform this, information data bits are multiplexed by spreading code [1]. At this stage, near-far problem occurs which degrades performance of CDMA system. To address this issue, matched filter systems are applied in conventional CDMA system where original signal is demodulated to meet the communication and user requirement. However, near-far problem can be addressed by using power control strategies where input signals are considered in a similar base station. Power control based techniques fails to provide significant performance when more number of communicating users are present hence more number of users causes more error into original signal. This stage is known as Multiple Access Interference (MAI) in CDMA communication systems.

Generally, these issues are addressed using orthogonal coding schemes are considered as promising techniques but for these techniques suffer from the performance issue for asynchronous CDMA communication modules by inducing multipath communication delay for end-user experience. Recently, multiuser detection scheme is considered as a significant approach for improving the communication quality by reducing communication during interference. Bui et al. [2] developed a new approach for multiuser detection using Gaussian process for CDMA systems. During this process, less number of training sequences are utilized which also provides notable performance for real-time communication systems equipped with CDMA model. Computational complexity is also a well-known issue which need to be addressed for providing faster and reliable communication. Gondela et. al. [3] discussed about multiuser detection schemes for DS-CDMA (Direct Sequence-Code Division Multiple Access) and presented multiuser detection scheme for fading channel using learning based optimization algorithm to reduce the multichannel interference. This study shows that optimal solution for multiuser detection can be obtained by using nonlinear optimization problems. This non-linearity provides better analysis for short spreading codes due to strong representation and fails for longer spreading codes. Moreover, multipath equalizers and radio frequency amplifiers helps to boost the nonlinear nature of multiuser detector model. This non-linearity issue increases computational complexity for CDMA multiuser detection system. Various techniques are presented to mitigate this complexity issue. Based on zero-forcing detector technique, Vishvaksenan et al. [4] presented a new scheme for MC-CDMA (Multi-Carrier Multiple Access Scheme). This technique considers turbo coded multi-carrier CDMA communication system for performance evaluation. This work uses channel information and vector quantization method for error rate reduction in CDMA systems. Similarly, minimum mean squared error (MMSE) also considered as a promising technique for multiuser detection in CDMA systems. Lamare et. al. [5] developed MMSE based scheme for DS-CDMA communication system by using iterative successive parallel arbitrated decision feedback (DF) receivers. A novel DF architecture is presented which helps to reduce the complexity by using successive cancellation for given communication system.

Along with these issues, power controlling is also a challenging task for real-time CDMA communication systems.This can also help for interference management and allocation of available resources for both downlink and uplink transmissions for

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CDMA communication [6]. According to power controlled process, QoS (Quality of service) for each user is obtained by using a limited amount of power used for transmission which doesn't cause any interference to other communicating user resulting in improved performance of communication. Youngju et al. [7] presented a power controlled scheme of wo-tier networks which contains femtocells and macrocells for network formulation. In order to obtain this objective, spectrum reuse technique is applied for femtocell model. This technique provides complete information for considered femto cells in the network and helps to mitigate cross interference caused between macrocells and femtocells. Similarly, Andrews et. al. also presented a power control mechanism for CDMA communication system which is based on MMSE and successive interference cancellation scheme. For power controlled process, SIR (Signal to interference-pulse-noise ratio) is measured for analysis. in order to desired SIR, transmit power for each user is adjusted in linear order hence computational complexity can be reduced during real-time communication system. Generally, power control scheme is considered as an optimization problem under predefined QoS constraints. Power consumed by one user can affect other user's performance hence minimization of total power consumption for each user is a challenging task along with multiuser detection by satisfying all QoS constraints. Shamai et al. [9] presented a power aware strategy for code-division multiple-access (CDMA) considering frequency-flat fading scenario for large number of users. However, a sufficient amount of work has been carried out in this field of CDMA communication system by addressing multiuser detection and power controlled strategies. Due to increasing demand of communication, number of users and network is also increasing rapidly which consumes more power during communication and fails to meet the criteria of multiuser detection which degrades the overall communication performance.

To overcome these issues of power consumption and multiuser detection, a new approach is developed in this work. According to this article, first of all a CDMA communication model is formulated. In the next phase, multiuser detection scheme is implemented for interference reduction and finally, optimized game theoretic approach is implemented to address the issue of power consumption in CDMA systems for providing efficient real-time communication. The main contribution of this work are as follows:

- ✓ CDMA communication system modeling
- ✓ Developing a technique for multiuser detection for CDMA
- ✓ Implementation of game theoretic approach for developing a power aware CDMA communication system.

Rest of the article is organized as follows: section II presents recent studies in this field of CDMA multiuser detection and power aware communication. Proposed two-fold strategy is presented in section III to mitigate the power and multiuser detection. Performance study and comparative analysis is presented in section IV and finally article is concluded in section V.

2. Related Work:

In this section we present a brief discussion about recent trends and technologies in the field of CDMA communication systems. Recently, various techniques are developed to address the issue of interference in CDMA. Bao et al. [10] developed a similar approach for $SC-FDMA$ (Single-carrier Frequency-Division Multiple Access) system for enhancing 5g communication technology. In FDMA communication systems, frequency variation causes more interference. Conventional techniques such as serial interference cancellation and iterative mechanisms fails to provide satisfactory performance for large number user communication model. Hence, this work presents a weighted approach for cancellation of parallel interference for real-time CDMA model. For multiuser detection zero-forcing technique has attracted researchers due to its significant nature and robust performance. Multiuser detection schemes can improve the performance for multiuser MIMO communication networks also. MIMO communication performance depends on spectrum efficiency parameter. To address this issue of improving the spectrum efficiency, Zhang et al. [11] presented a low complex scheme for $MIMO-OFDM$ communication. This scheme is a combination of zero-forcing and interference cancellation techniques. According to this study, orthogonality causes co-channel interference which is mitigated using block diagonalization technique. Moreover, computational complexity is also reduced by applying SVD (singular value decomposition) technique. In [12], Wang et al. discussed about multiuser detection for DS-CDMA application using Gaussian technique. This technique uses minimum mean square error criterion. Furthermore, sparse spectrum Gaussian process is also introduced for multiuser detection purpose. Sparsity functionality helps to build a low complex approach for multiuser detection when compared with Gaussian process and achieves better performance in terms of BER (Bit Error Rate). Similarly, multicarrier code division multiple access is also suffer from the issue of multiuser detection. Jia et. al. [13] introduced an adaptive frequency approach for MCCDMA systems. This technique provides better spectral efficiency which has become a key interest for researchers. Prior to this technique, water-filling algorithm is also discussed but water-filling algorithm fails to address the fading and near-far problem. Hence this technique is improved by using matched filters at receiver end of the module.

Nonlinear multiuser detection became a challenging task for researchers due to its complexity issues. To address this issue, Murillo et al [14] developed a Gaussian regression based approach for CDMA multiuser detector systems. This work develops a non-linear multiuser detection system using Gaussian regression technique. Gaussian regression model helps to formulate an analytical model for multiuser detection system and helps to compute the non-linearity parameters with the help of maximum likelihood.Moreover, Gaussian regression model computes non-linear parameters which does not need to solve the optimization problem to formulate non-linear estimator hence faster computation is incorporated in CDMA system along with multiuser detection where MMSE detector systems are used for linear decision function formulation. In CDMA communication system scenario, during real-time communication it is considered that all users are independent to each other and identically distributed over a communication field whereas in multiuser communication system, data sequences can be transmitted to various users and these sequences are time correlated. In this scenario, conventional techniques fail to provide efficient communication. in order to address this issue, Chen et. al. [15] developed a new approach where time correlated signals are modeled as first-order problem

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and converted into finite-state markov chains. Multiuser CDMA model generates interference which is addressed using linear filter based on the maximum target likelihood criterion. In this work, Hidden Markov Model is also applied to maximum target likelihood which helps to estimate data sequence, noise variance in data and transition probability for each user.

Along with multiuser detection, power consumption during real time communication becomes a challenging task which need to be addressed for providing better communication performance. Since, in this work our main aim is to develop a technique for CDMA communication system which can support CDMA communication in terms of power controlling and multiuser detection process. Various works have been presented in this field of power controlling for CDMA communication system. For CDMA power control, Bacci et. al. [16] paper introduces a game-theoretic approach to the issue of power allocation for the uplink of a flat-fading code division multiple access (CDMA) wireless communication network, in which terminals already code-locked to the access point coexist with some terminals still in the code acquisition stage. To capture the tradeoff between obtaining good performance and saving as much energy as possible for both classes of terminals, we propose a noncooperative game with strict incomplete information (i.e., a pre-Bayesian game) based on an energy-efficient criterion that depends on each terminal's status. This formulation allows us to derive an iterative and distributed algorithm that enables each terminal to locally regulate its optimal transmit power without any knowledge about all others' operating status.

Janatian et al [17] we investigate the power allocation issue for cooperative-sensing-based code-division multiple access (CDMA) cognitive radio (CR) networks. We consider a network consisting of multiple secondary users (SUs) and a secondary base station (BS) implementing a two-phase protocol. In the first phase, censor-based cooperative spectrum sensing is carried out to detect the PU's presence. When the channel is estimated to be free, SUs transmit data in the uplink to the BS in the second phase by using CDMA. We optimize the sensing parameters and transmit power of SUs jointly to minimize the total energy consumption with the constraints on SUs' quality of service (QoS) and detection probability of the PU. This is a nonconvex problem, which we represent as a monotonic optimization problem and solve by means of monotonic programming. Furthermore, we study the separate optimization problem in which sensing parameters and transmit power are optimized to minimize the energy consumption of the first phase and the second phase disjointly. Numerical results show that the proposed joint optimization method saves energy consumption significantly in lower signal-to-noise ratios (SNRs).

3. Proposed Model:

Proposed approach is mainly concentrated on power controlling and multiuser detection for CDMA which can improve the overall communication performance. Complete modeling of proposed approach is presented in this section. First of all, CDMA modeling is presented which is considered for further processing.

3.1 CDMA Modeling: Here we present a CDMA model for data transmission and reception conisderations. General architecture of DS-CDMA is depicted in figure 1.

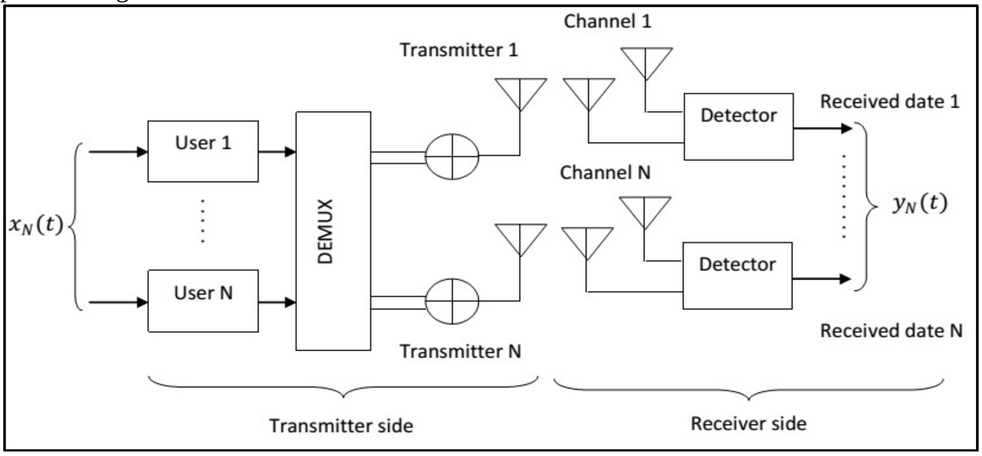

Figure 1: DS-CDMA architecture

According to this CDMA model, total $\mathcal{N}$ number of users are conisdered and transmitted signal of $\mathcal{N}^{th}$ user is denoted by $x_{\mathcal{N}}(t)$ and similarly recived signal is denoted as $y_{\mathcal{N}}(t)$. Binary data which is transmitted by $\mathcal{N}^{th}$ user is denoted as $a_{\mathcal{N}}(t)$. According to CDMA system architecture, transmitted side contains user data and demux whereas receiver side contains communication channels and detectors. In this model, transmitted signal can be denoted as follows:

$$x_{\mathcal{N}}(t) = \sqrt{\mathcal{R}_{\mathcal{N}} * 2}a_{\mathcal{N}}(t)e_{\mathcal{N}}(t)\cos(f_c t + \theta_{\mathcal{N}}) \quad (1)$$

Where $a_{\mathcal{N}}$ is transmitted signal, $e_{\mathcal{N}}(t)$ is the spread signal, $\mathcal{R}_{\mathcal{N}}$ is signal powerand f_c is carrier frequency. Further this can be represented as :

$$a_{\mathcal{N}}(t) = \sum_{i=-\infty}^{\infty} a_{\mathcal{N},i}\, r_T(t - iT)$$
$$e_{\mathcal{N}} = \sum_{j=-\infty}^{\infty} e_{\mathcal{N},j}\, r_{T,c}(t - iT_c) \quad (2)$$

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$\theta_{\mathcal{N}}$ denotes phase of $\mathcal{N}^{th}$ communicating user, r_T denotes rectangular pulse,$r_{T,c}$ denotes clip rectangular pulse and T is known as bit duration. During communication, transmitted signal is passed through demux block which is formulated by combning $a_{\mathcal{N}}(t)$and signature of spread signal. In the next stage, processed signal is obtained from demux where processing gain is estiamted which is depend on the clip and bit duration. Finally, received signal by user can be expressed as follows:

$$y_{\mathcal{N}}(t) = \sum_{\mathcal{N}=1}^{\mathcal{M}} \sqrt{\mathcal{R}_{\mathcal{N}} * 2} a_{\mathcal{N}}(t-\lambda_{\mathcal{N}}) e_{\mathcal{N}} \cos\big(f_c(t-\lambda_{\mathcal{N}})\big) + \theta_{\mathcal{N}} + g(t) \quad (3)$$

In another way it can be represented as:

$$a_{\mathcal{N}}(t-\lambda_{\mathcal{N}}) = \sum_{i=-\infty}^{\infty} a_{\mathcal{N},i}\, r_T\big((t-\lambda_{\mathcal{N}}) - iT\big)$$

And signature spread signal can be given as (4)

$$e_{\mathcal{N}}(t-\lambda_{\mathcal{N}}) = \sum_{j=-\infty}^{\infty} e_{\mathcal{N},j}\, r_{T,c}\big((t-\lambda_{\mathcal{N}}) - iT_c\big)$$

3.2 Multiuser Detection: Let us generalize DS-CDMA uplink model for multiuser detection purpose for total $\mathcal{N}$ users and S spreading factor where transmit power, channel gain and background noise variance is denoted by p_n , h_n and σ^2 for $\mathcal{N}^{th}$ user. For this user, received signal to noise ratio can be expressed as $\alpha_k = \frac{p_n h_n}{\sigma^2}$. Hence, received signal can be represented as:

$$Y = W + SX = \sum_{n=1}^{\mathcal{N}} \sqrt{\alpha_n} X_n S_n + W \quad (5)$$

X_n is transmitted symbol, S_n is a spreading sequence (in a vector form such as $\mathcal{N} \times 1$) and W is considered as noisy component which contains independent and identically distributed Gaussian entries.
Let us consider that receiver is a linear filter denoted by c_n, detection output can be given as combination of three components such as:

$$\widehat{X_n} = c_n^T Y = \sqrt{\alpha_n}(c_n^T S_n) X_n + MAI_n + V_n \quad (6)$$

In this process, output signal quality is measured by computing SIR. Multiple access interference is asymptotically Gaussian in nature hence relationshipfor MAI is given as follows:

$$\gamma_n = \frac{\alpha_n (c_n^T S_n)^2}{c_n^T c_n + \sum_{j\neq n} \alpha_j \left(c_k^T S_j\right)^2} = \eta_n \alpha_n \quad (7)$$

Due to asymptotic nature of MAI, SIR is not greater than considered SNR value. In this model, multiuser efficiency is obtained by estimating degradation factor denoted by η_n. This model helps to develop an efficient detection scheme with reduced complexity in CDMA implementation. In next stage, we implement power control or power aware strategies. In order to implement this, first of all a power control model is developed in the form of optimization problem and in next we implement game theoretic approach for controlling and optimization scheme by implementing non-cooperative game theory model.

3.3 Power Controlling Model for CDMA: This section provides power controlling methdology for power controlling scheme for CDMA systems. In order to formulate this, a game theoritic approach is implemented here using non-cooperative game formation. According to non-cooperative power modeling scheme each user tends for utility maximization resulting in improved performance of system. This utility for n user can be defined as follows:

$$u_n = \frac{T_n}{p_n}\ (bits\ per\ joule) \quad (8)$$

Where T_n denotes total number bits to be delivered in a given time constraints for each user n which represents goodput for system. This utility function helps to estimate the tradeoff between energy and throughput. Due to this advvatngeous nature of scheme, it makes it more suitable for real-time energy efficiency demanding systems. For throughput maximization, throughput can be defined as

$$T_n = \frac{RL}{M} f(\gamma_n) \quad (9)$$

Where rate of data transmission is denoted by R, L denotes total number of information bitss and total number of bits in information packet is denoted by M. These bits are independentof γ_n and $f(\gamma_n)$ and known as efficiency fuction representing the success rate of data transmission at γ_nSIR. In this work, it is assumed that error packets are retransmistted for maintaining the quality of communicaiton. In order to optimize the power, utility function is used for each user which is given in the form of transmit power as follows:

$$u_n(p_n) = \frac{RL * \big(f(\gamma_n)\big)}{M * p_n} \quad (10)$$

As dicussed before that efficieny of this technique is measured by conisddering function denoted as $f(.)$ Which is having two points where it increases in concave and convex nature. Upper point is known as convex and below point is denoted by concave point. Later it is also assumed that $f(\infty) = 1$ and $f(0) = 0$. With the help of these assumptions, non-cooperative game can be expressed as:

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$$0 \le p_n \le P_{max} \max u_n \; for \; n = 1, \dots, \mathcal{N} \quad (11)$$

P_{max} is maximum allowed power. In order to aid this non-cooperative strategic game, power controlling can be addressed by obtaining Nash Equilibirium condition. In next subsection, Nash equilibirium is presented for power controlled CDMA communication model.

3.4 Nash Equilibirium: In previos section, multiuser detection is implemented. In order to obtain other objective of this work i.e. power control Here our main aim is to implement a Nash Equilibirium solution for CDMA model which can help to improve the resource allocation for each user. Let us considder that each user n faces a distortion given as $\mathcal{E}\{D_{s+c}, n\}$, utility function for this case can be defined as:

$$x_n = \frac{c}{\mathcal{E}\{D_{s+c}, n\}} \quad (12)$$

Where c is a positive constant. Let X be a vector such as $\{x_1, x_2, \dots, X_N\}$ which consist information about each usech user and it is assumed that this vector in convex in nature and upper bounded in nature. Due to the DS-CDMA nature, cross interference degrades communication quality and causes more power consumption for desired communication hence a controlled moddule is required which can help to analyze the demand and can assign power accordign to the controlled parameters. This process is called as negtiation in game theroy approach which is responsible for providing efficient utility for each user independently. In huge communication scenario, a disagreement point is also presented given as $d = (d_1, d_2, \dots, d_K)$. This disagreement pont provides sufficient information to each node for making deal independdently for utility maximization. In this work, finding the disagreement point d is a crucial task resulting in optimal power allocation for commncation. This iptimal power allocation is obtianed in between source and channel coding for each node, this state is known as *Nashequilibirium*. In order to maximize the communication quality, each noderequires more power. In order to address this issue of power consumption, we define a bargain set using all elements of input symbols for improving the payoff. The Nash Bargaining Solution $F(\boldsymbol{X}, \boldsymbol{d})$ is a member of the bargaining set that satisfies the following axioms:

- ✓ $d \le F(X, d)$
- ✓ $F(X, d) < y \rightarrow y \notin X$
- ✓ Apply increasing affine transmform such as $\intercal(.)$, $F(\intercal(X), \intercal(d)) = \intercal(F(X, d))$
- ✓ If $d \in Y \subseteq X$ then $F(X, d) \in Y \rightarrow F(Y, d) = F(X, d)$

Initial two conditions show that each solution for given power optimization problem should lie in the given bargaining set. For finding the Nash bargaining solution, source coding, channel coding and power consumption for each node need to be computed which is given in a vector form as $x = (x_1, x_2, \dots, x_K)$ and maximized product can be given as:

$$F(X, d) = \underset{x}{\arg\max} (x_1 - d_1)^{\alpha_1} (x_2 - d_2)^{\alpha_2} \dots (x_K - d_K)^{\alpha_K} \quad (13)$$

The above equation is subjected to $x \ge d$ where it is also assumed that α_i is the bargaining power of conisdered user i which helps to estimate the weightage of communicating user and finds that the particular user is advantageous for communication or not. In proposed approach, each user is conisdered with equivalent propoerties hence intially none of the user is assigned as more advantageous by assigning $\alpha_i = 1$ for each user. With the help of this assumption, Nash product can be written as

$$F(X, d) = \underset{x}{\arg\max} (x_1 - d_1) (x_2 - d_2) \dots (x_K - d_K) \quad (14)$$

In order to compute the Nash Equilibrium solution, first of all vector d need to be computed such as $d = (d_1, d_2, .. d_K)$which contains maximum utility for each data sequence and estimates the maximum power after estimation d. Further, the main aim of this approach is to maximize the Nash equilibrium and finding the optimal power solution in given network configuration scenario.

4. Result and Discussion:

This section provides complete simulation study of proposed model using CDMA system. Proposed multiuser detection power control model is implemented using MATLAB platform. For modulation consideration, BPSK technique is utilized at transmitter side. Performance analysis is carried out into two parts: first of all, multiuser detection is performed and then power controlling is addressed for multiuser CDMA communication system. Overall performance of proposed system is measured using BER (bit error rate) measurement technique. Simulation parameters are given in table 1.

Simulation Parameter	Considered Value
Total number of users	10,20,30,40,50
Modulation Type	BPSK
Signal processing gain	50
Spreading sequence	50
Signal to noise ratio	[0,20]
Total number of bits to be transmitted	10^2
Carrier frequency	1.8 GHz

First of all, BER performance of proposed model is evaluated whereSNR is varied from 0 to 20 with BPSK modulation scheme.

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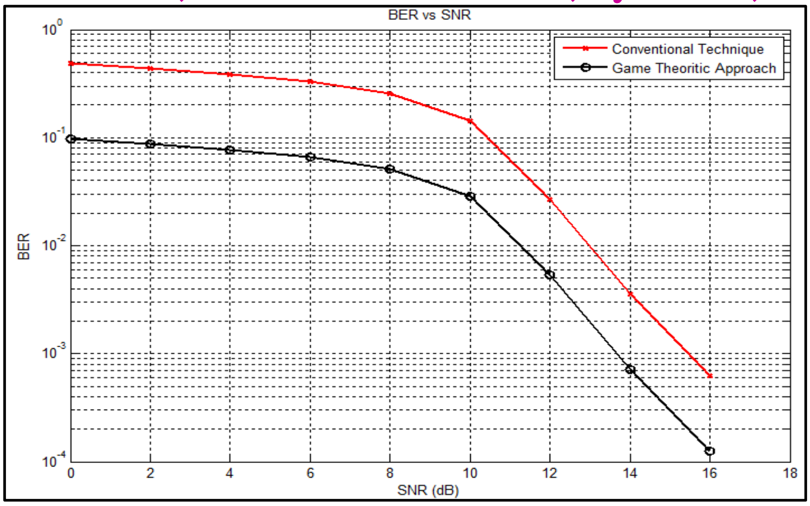

Figure 2: BER vs SNR performance

According to figure 2, proposed game theoretic approach achieves better results for BER whereas conventional technique does not provide promising results. This performance is carried out for 10 users, similarly this analysis can be performed for more number of users. In order to show the robustness of proposed approach, we present average BER performance for varied users. This analysis is depicted in figure 3.

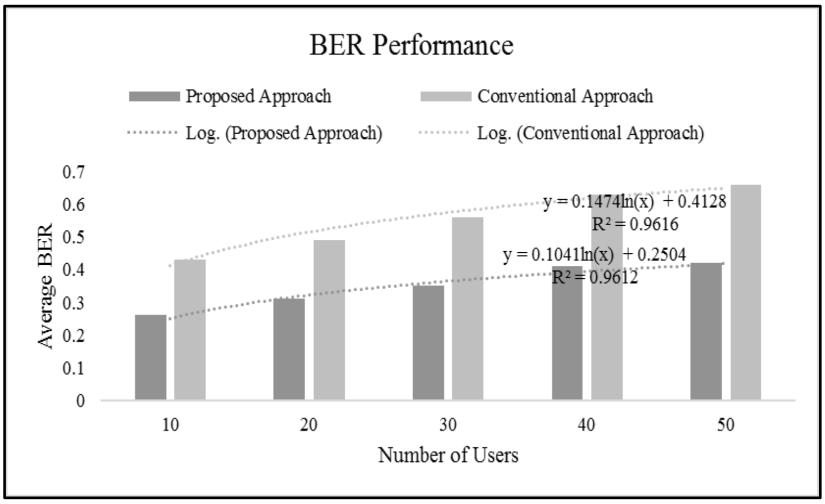

Figure 3: Average BER vs SNR performance

Moreover, logarithmic analysis is also given in figure 3 where *R* squared values are also given in equation form. This analysis shows that proposed approach gives better performance in terms of BER for multiple user CDMA system. Similarly, power analysis is also carried out for multiple user scenario where users are varied and performance of proposed and conventional technique is compared. This analysis is carried out in terms of outage probability. Overall performance of outage probability is given in figure 4. Initially, this analysis is performed for varied SNR as depicted in figure 4.

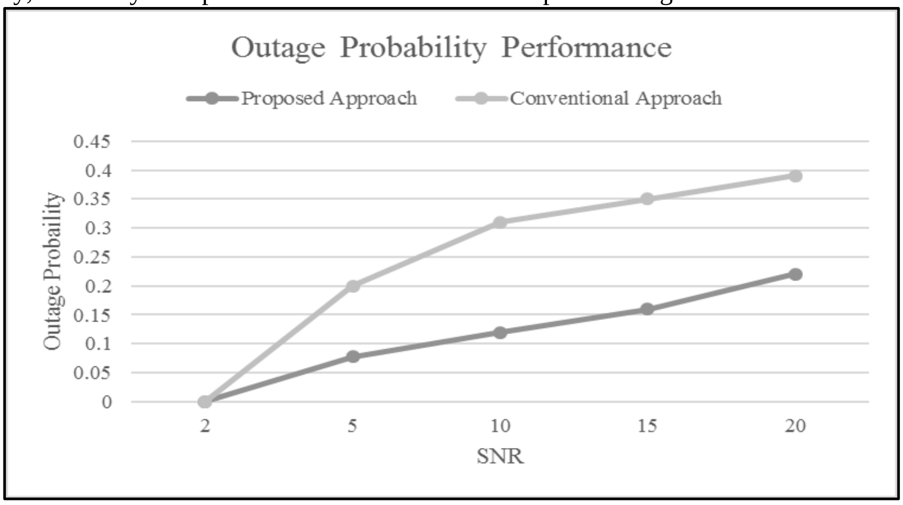

Figure 4: Outage Probability Performance

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Finally, figure 5 shows outage probability performance for varied number of users as depicted in figure 5. This analysis shows that proposed approach provides significant improvement when compared with conventional power aware techniques for CDMA system.

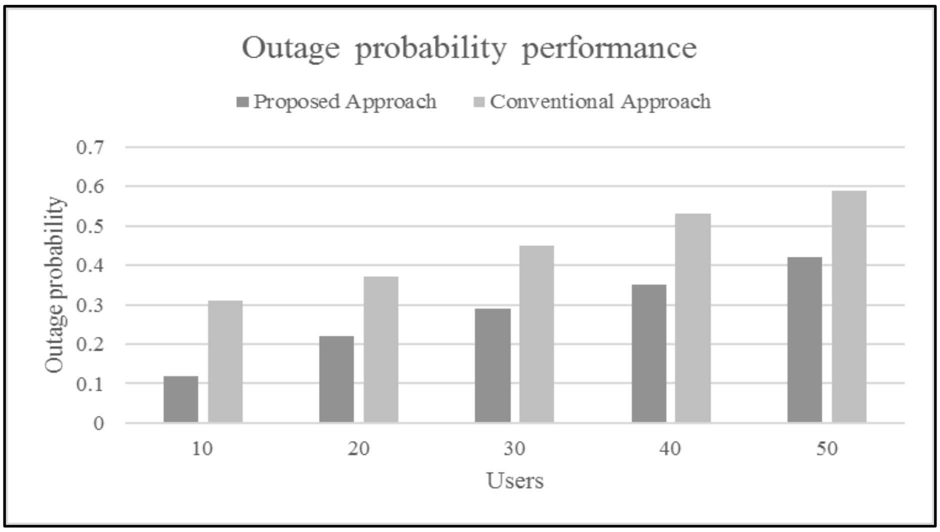

Figure 5: Outage probability performance for varied user

5. Conclusion:

This work presents a simulation study about CDMA systems and analyzes multiuser detection and power controlling issues during real time communication in CDMA.In order to carry out this work, game theoretic approach is implemented for CDMA systems. This approach helps to reduce the information loss in CDMA. Along with multiuser detection, here power control and BER performances also carried out which shows that proposed approach gives robust performance for varied communication scenarios. The complete approach depends on the Nash Equilibrium scenario which provides an optimal solution for allocation of available resources and reduces power consumption. Proposed approach is compared with existing Gaussian regression based techniques. Simulation study shows that proposed approach gives better performance when compared with state-of-art technique of power controlling in CDMA system.

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