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Doppler and Raleigh Fading effects on outage probability performance for the Optimal Power Control of CDMA Based on BFA

Abubakar Bala[1], Jibrin Danladi Jiya[2], Sa'id Musa Yarima[2], Kabiru Adamu Sa'idu[3], Suleiman Abdulkadir Baraza[4]
[1] Department of Electrical and Electronics Engineering, Nigerian Army University Biu, Borno State, Nigeria
[2] Department of Electrical and Electronics Engineering, Abubakar Tafawa Balewa University Bauchi, Bauchi State, Nigeria
[3] Department of Electrical and Electronics Engineering, Federal Polytechnic Kaltungo, Gombe State, Nigeria
[4] Department of Electrical and Electronics Engineering, Abubakar Tatari Ali Polytechnic Bauchi, Bauchi State, Nigeria

Abstract

Owing to the fact that wireless communication has an edge over its wired counterpart in terms of low cost and ease of deployment, transmission principles in wireless communications are actually more complex due to the mobile radio channel that imposed a potentially massive limitations on the system performance. A mobile communication system employing code division multiple access (CDMA) also suffers channel impairment due to interference during propagation that reduced the overall system performance and therefore system quality of service (QoS). As the system QoS is interference-limited, a power control problem can be formulated as nonlinear optimization with a system-wide objective subject to power constraint. This paper focuses on multi-objective power control based on bacterial foraging algorithm (BFA) technique to combat adverse effects of excessive time-varying interferences such as channel fading, multiple access interference, round-trip delay and noise in a CDMA system. This is aimed at achieving higher communication link quality, better system capacity, improved battery power and reduce outage probability under time-varying interference Raleigh fading channel and Additive white Gaussian noise at the input of the receiver. This paper also examines the performance of the power control technique for different mobile velocities at the high interference environment and the outage performance was found to be very small.

Keywords: CDMA, Bacterial Foraging Algorithm (BFA), Quality of Service (QoS), Doppler Effect, Raleigh Fading Effect

Introduction

Code Division Multiple Access (CDMA) systems are attractive multiple access scheme where users are isolated by codes rather than by frequency or time as in the case of frequency division multiple access (FDMA) or time division multiple access (TDMA). As such, Direct Sequence Code Division Multiple Access (DS-CDMA) technology is a spread spectrum technique that uses neither frequency channels nor time slots where the narrow band message (digitized data to be transmitted) is multiplied by a large bandwidth signal that is a pseudo-random noise code (PN code) for transmission (Bala *et al*., 2019) [3]. The DS-CDMA technology is quite robust to frequency selective fading, good advantages to interferer diversity and flexibility and the scheme was successfully introduced in the commercial cellular mobile communications systems that include; 3G, 4G, LTE and LTE However, the user's signal waveform usually suffers a huge cross-correlation with other users' signal due to time-varying fading channels with time-delay effects; this is a phenomenon called multiple access interference (MAI) (Bala *et al*., 2019) [3]. The other critical problem of CDMA is the competition between mobile close to base station (BS) and those far away from it.

Literature review

Power control in wireless CDMA system considers multiple objectives much more than the single objective ones. Elkamchouchi *et al*. (2007) [10] proposed a multi-objective optimization algorithm for power control of CDMA system based on particle swarm optimization (PSO) to minimize three objectives; power consumption, energy-per-bit-per noise and near far effect in a more effective way to obtain the optimal power vector that satisfies all the objectives. Elmusrati *et al*. (2007) [13] envisaged a multi-objective optimization method for the power consumption and tracking error deviation minimization, while Elmusrati *et al*. (2008) [12] proposed a novel analytic approach for multi-objective optimization of distributed power and rate control trade-off between resources in radio resource scheduler (RRS) using an algorithm that relaxes the constraints and jointly optimizes all the required objectives; power consumption, tracking error deviation and throughput. Moreover, Yang and Cheng (2013) proposed power control scheme that simply adjust transmit power and achieve the best compromise between, SINR deviation, power consumption and the system outage. As an alternative, Genetic algorithm-based optimization technique for power control was envisaged to solved two objectives; power consumption and tracking error which determines the optimal power control for users in a quite flexible and accurate manner (Song *et al*., 2012) [19]. A different approach was used by Chen *et al*. (2006) [7] for the power control of CDMA system based on robust state feedback control via a desired pole placement and an l_1 optimal predictor that predicts tracking error and compensate effects arising from uncertainties such as channel fading, interference and noise which are reduced to a smallest possible level, and achieving the desired SINR.

A successive interference cancellation multiuser detector was proposed (Molina *et al*., 2018) [17]. The work is aimed at maximizing throughput under high traffic condition. Another work on the performance of distributed power control algorithms in uplink of CDMA system was evaluated in (Fakroon, 2018) [14]. Farzamnia *et al*. (2020) [15] envisaged a non-cooperative reversed link power control for CDMA system. But Wu *et al*. (2021) proposed a mean-field power control emphasis on CDMA and non-orthogonal multiple access (NOMA) systems.

1. Dynamic Radio Environment for Received Signal Power of a CDMA System

In wireless communication multipath fading and shadowing phenomenon are encountered in different scenario as they reduce the performance of the system. In a typical CDMA system, the transmitted signal suffers various kinds of channel impairments, from path loss, fading, noise and interference as well. Thus with tight power control, the signal adapts to the changing attenuation of the desired signals, as well as the changing interference conditions (Wu *et al.*, 2021), owing to the fact that the attenuations of the co-channel users' signals are also changing and those signals are power-controlled as well. This signifies the fact that the task of the power control technique is to vary the mobile transmit powers in order to recompense for the varying channel attenuations, so that the signals from the different mobile stations are received with equal powers (same mean power level) at the base station (Bala *et al.*, 2019) [3].

3. Methodology

3.1 Bacterial Foraging Algorithm

The basic approach involved in BFA optimization algorithm is to find the minimum of cost $\{J\ (\theta)\}, \theta\ \in R^p$ that gives information about the gradient $\nabla J(\theta)$ is not available, θ is the position of the bacterium and $J(\theta)$ represents an attractant-repellant profile which provides the cost value (Bala *et al.*, 2022-1) [5]. Where the nutrient and noxious substances are located in various positions of the nutrient profile: $J < 0$, $J = 0$, and $J > 0$ represent the presence of nutrients (good cost), a neutral medium (ordinary cost) and the presence of noxious substances (poor cost), respectively (Passono, 2002). The foraging process the bacteria undergo are: chemotaxis, swarming, reproduction, and elimination and dispersal (Bala *et al.*, 2022-2) [5].

2. Channel Model

The reverse communication link channel for i-th mobile user can be characterized by a power gain, G of path between the base station (BS) and the mobile station (MS). This gain, G is affected by three main parameters. These are: path loss, shadowing and multi-path fading. To achieve a good communication link through each channel characterized by the gain, G, the information is transmitted using a power level $P_i(k)$ and the receiver detects a power signal $P_r(k)$ related to the i-th user given by (Bala *et al.*, 2019) [3];

$$P_r(k)\ = P_i(k)G_i(k) \tag{1}$$

Where, $P_i(k)$ is the mobile transmit power of user i and $P_r(k)$ is the BS received power.

Using SINR type metric as the quality of service (QoS) measure of the i^{th} user measuring indices and also focusing on uplink (reverse) system, the received signal quality at a receiver can be reliably measured.

3. Doppler Effect

Doppler Effect is due to the motion of the mobile station. the speed of the mobile results from the relative motion between the transmitter (MS) and the receiver (BS) causes a random frequency modulation, owing to the effect of different Doppler shifts (frequency shift of each portion of transmitted waves) on each of the multipath components (Barsocchi, 2006) [6].

The Doppler shift is given by equation (2).

$$f_D\ \ = f_m\ \cos\phi_n \tag{2}$$

$$f_m\ = \frac{v}{\lambda_c} \tag{3}$$

Where f_m is the maximum Doppler frequency occurring when the incidence angle (angle of arrival of the incident wave) ϕ_n = 0 and λ_c is the wave wavelength of arriving plane wave (Bala *et al.*, 2019) [3]. The maximum Doppler shift or frequency depends on the ratio of the speed of the vehicle (v), the speed of the light (c), and the carrier frequency (f_o).

4. Rayleigh Fading Effects

The Rayleigh fading channel model assume that the magnitude of transmitted signal that has passed through such a communications channel (Rayleigh fading channel) will vary randomly, or fade, according to a Rayleigh distribution; the radial component of the sum of two uncorrelated Gaussian random variables (Rahman *et al.*, 2016) [18]. The Rayleigh fading occurs when no line of sight (LOS) path exists between the transmitter and receiver, but only have indirect path than the resultant signal received at the receiver will be the sum of all the reflected and scattered waves (Nuzhat *et al.*, 2012).

$$f_{ray}(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right),\quad r \geq 0. \tag{4}$$

5. Channel Parameters

The channel parameters choice for the proposed CDMA system for calculation in this research work has the specifications shown in Table 1.

Table 1: Channel Parameters

Parameter (Symbol)	**Value**
Path loss exponent,($\boldsymbol{\alpha}$)	4.2 (Urban area)
MS to BS distance, ($\boldsymbol{\Delta_o}$)	500m to 5000m
Closed-in-reference distance, ($\boldsymbol{d}$)	1000m (1km)
Path loss at reference distance, ($\boldsymbol{A_{\Delta_o}}$)	20dB
Mean Gaussian random variable, ($\boldsymbol{\mu}$)	0
Gaussian random variable standard deviation, ($\boldsymbol{\sigma}$)	8dB
Additive White Gaussian Noise (**AWGN**)	$3.2\text{x}10^{-14}$ mW
Number of multi-path beams	20 (No LOS)
Number of base stations	19

Source: (Bala *et al.*, 2019) [3]

Results and discussion

1. Numerical Results

In this section, the detailed results concerning the determination of the round-trip delay, it is supposed that there are twelve (12) mobile users per cell which are made to stand in three groups of four, such that: users 1-4 used low data rates, users 5-8 used medium data rates and users 9-12 used high data rates. The channel parameters of ψ =0.01, high data rate R_3 = 921.6 *k*Hz, [P_i^{min}, P_i^{max}] = [-60dB*m*, 0dB*m*], §itar= -10dB, §imin = -14dB. A metric called the standard deviation of SINR tracking error was used to evaluate the system performance. The effect of the round-trip delay for the power control scheme was evaluated using several round-trip delays ($1T_s$ to $4T_s$) were set to simulate different situations. Again, a high data rate (277.778 Hz) and sampling period (T_s) of 1.0851s was used. On varying data rate for different mobile velocities, the channel fading f_i (k) depends largely on the mobile velocity and the fading variation becomes faster as the mobile velocity increases. Mobile velocities ranging from 50 to 150 *km*/*h* were considered in this work.

The interference power against number of active mobile users which reflects the results over fading, shadowing and Doppler situations is depicted in Figure 1.

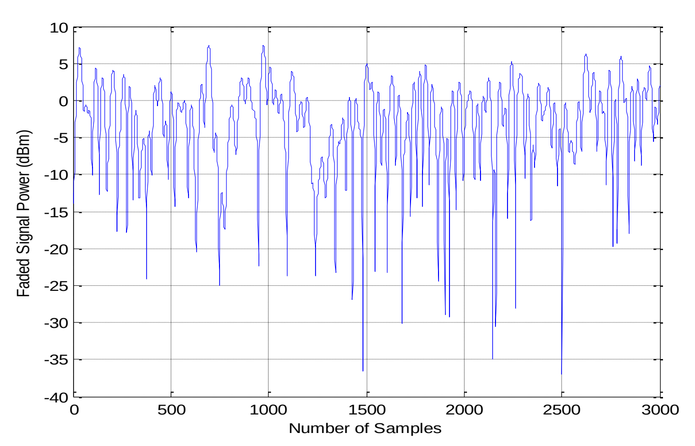

Fig 1: Faded Signal Power versus Number of Samples

Table 2 provides the parameters for Standard deviation tracking error for different round-trip delays to twelve active mobile users.

Table 2: Computed Data for Standard Deviation Tracking Error for Different Round-Trip Delays.

Round trip delay (d_i)	Standard Deviation Tracking Error, σ_e (dB)	
	BFA	STEM
$1T_s$	0.4101	0.4219
$2T_s$	0.4110	0.4230
$3T_s$	0.4121	0.4243
$4T_s$	0.4125	0.4251

Figure 2 depicts the plot for the standard deviation tracking error versus round-trip delay between the base station-mobile pair and shows that the standard deviation tracking error copes with different round-trip delays, which therefore provides a sufficient robustness to round-trip delay increment. This results to reduced MAI impairment effect and then low outage effect.

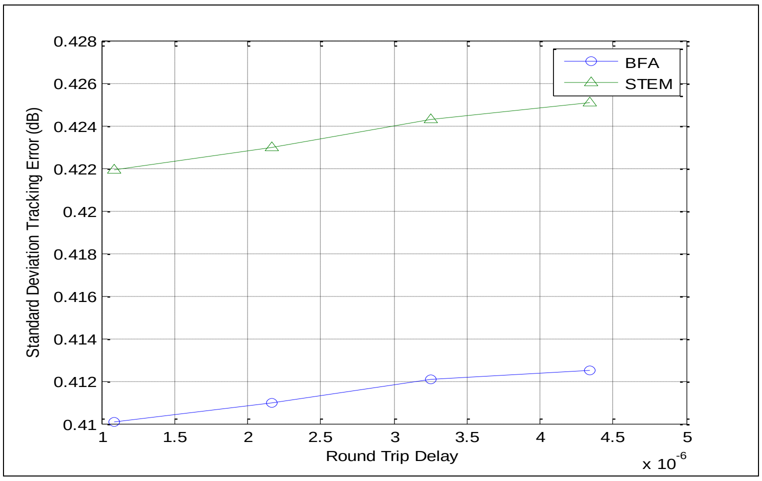

Fig 2: Standard Deviation Tracking Error versus Round-Trip Delay

Figure 3 shows that the system is capable of maintaining the standard deviation tracking error of all the mobile users at the optimum level. The variation of standard deviation tracking error σ_e based on BFA compared with STEM with mobile velocity is considered in Figure 8 for 12 active mobile users.

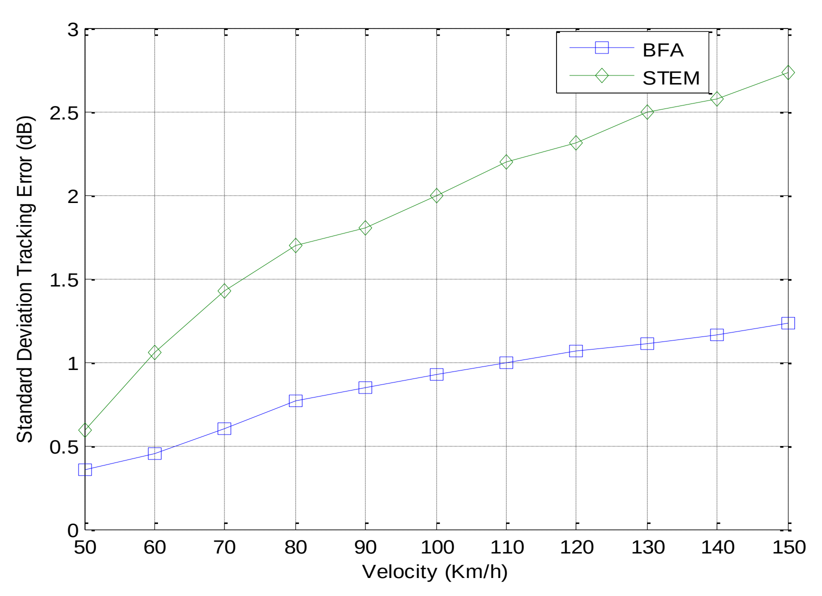

Fig 3: Standard Deviation Tracking Error σ_e versus Mobile Velocities

The method shows that for better velocity variation performance is achieved using different rates as it compensates for the effect of Doppler Effect. Clearly, standard deviation tracking error increases for increasing mobile velocity and indicates that lower values of standard deviation tracking error for all mobile velocities are obtained for all channel situations. This thereby shows little MAI and then low outage value possibilities.

Again, from the plot of in Figure 4, the BFA have shown an effectiveness in power control optimization scheme as appreciable optimal mobile transmit powers for increasing number of users were obtained in the presence of round-trip delay, uncertain interference, and AWGN noise.

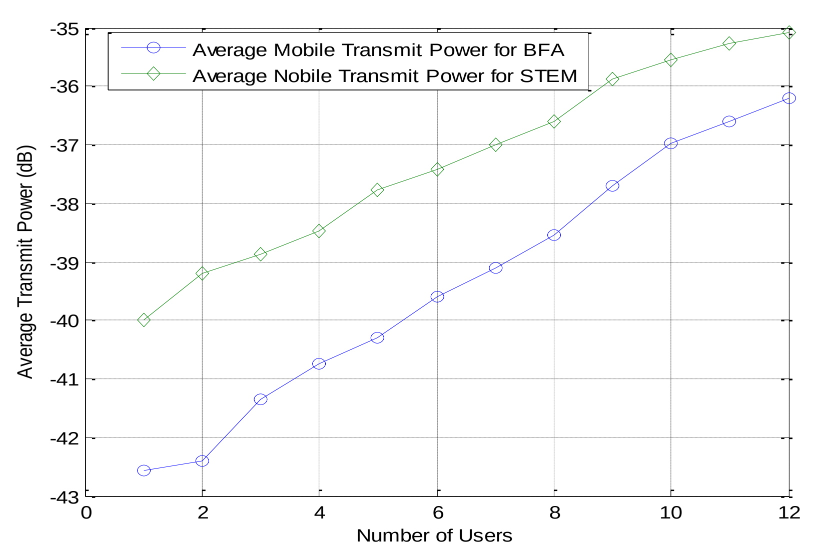

Fig 4: Average Mobile Transmit Power versus Number of Users per Cell.

From Fig 4, it is clear that the proposed BFA power control scheme estimates the optimal target SINR that is largely proportional to the average mobile transmit power which is a special requirement for the system QoS. This ultimately signifies that the proposed multi-objective optimization scheme yields good results.

The outage probability is an important performance index in a CDMA system owing to its capability to measure how the SINR falls below a prescribed threshold level i.e. percentage of users failing to achieve the minimum tolerable SINR level (Bala *et al.*, 2019) [3]. It ensures the better traffic capacity and improved QoS. The effects of outage probability curve for the proposed system is shown in Figure 5 with respect to the average mobile transmit power.

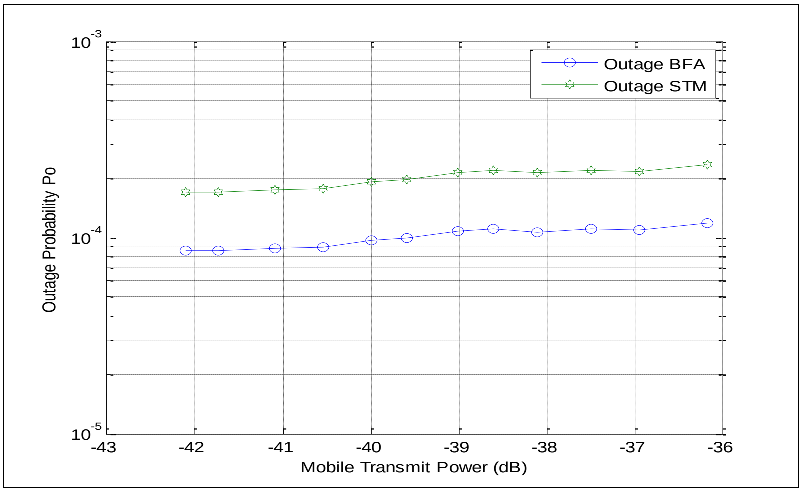

Fig 5: Outage Probability versus Number of Mobile Users

Fig 6 shows the outage probability against users.

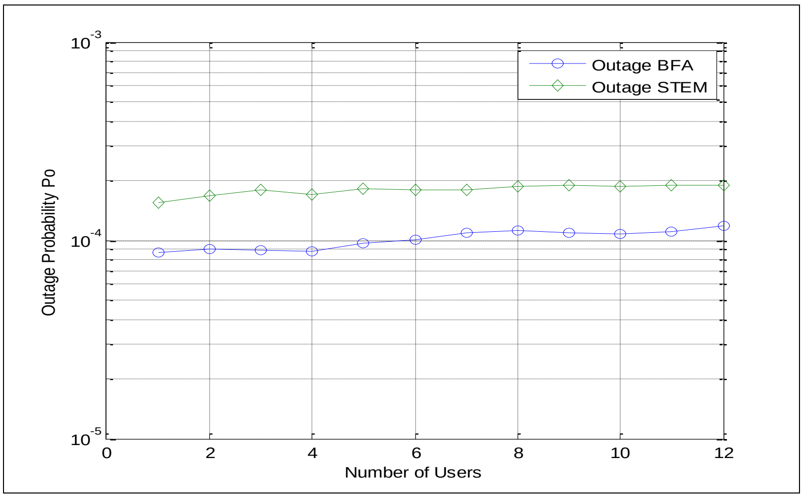

Fig 6: Outage Probability against Users

From the Figure 6, it was clear that the propose method shows lower outage probability values for all the 12 number of users. Clearly, the propagation loss, fading, AWGN and the Doppler effects have less significant effects on the outage probability performance owing to tight power control employed which came up optimal mobile transmit power. Increasing Doppler frequency for increasing number of users yields lower values of outage (Figure 6), which shows effectiveness of the method.

The outage probability versus mobile velocity is plotted in Figure 7. It can be seen that the proposed method achieved lower values of outage probability than the other scheme, owing to the fact that the work considers the minimal system outage as one of the objectives in the cost function formulation.

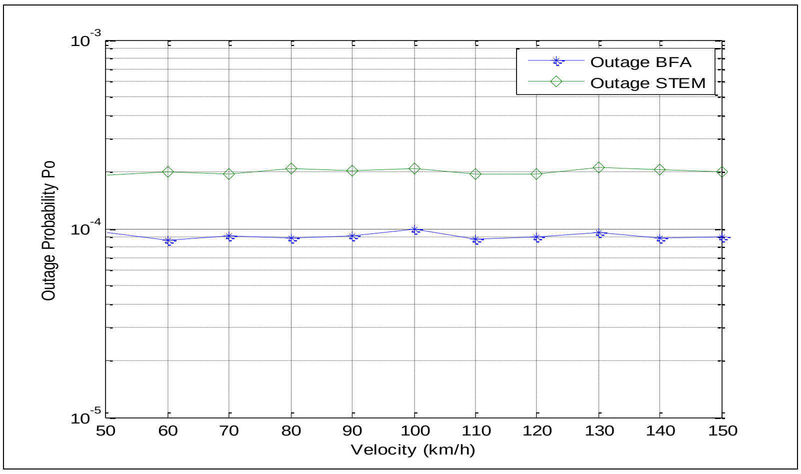

Fig 7: Outage Probability against Velocity

This clearly portrayed the fact that the consideration of MO optimization in this work reduces the effect of the system outage. Along way, MAI becomes less amidst fading effect, signifying the system robustness to channel parameters variation.

Conclusion

This work focuses on an uplink power control problem for wireless CDMA communication system when large number of users compete for the channel resources in a typical rayleigh fading channel and AWGN, making users to operate at a very high velocity and high interference environment. The power control problem presented shows that the bacterial foraging algorithm used have fast converging time, produced minimum mobile transmit power vector needed to achieve the target SINR to all users and low outage probability with the assumption of transmission in time-varying fading channels with time-delay effects. Therefore, a study on CDMA power control optimization can be considered for future work in improving the spectral efficiency and bit error rate performance (high throughput) so as to make CDMA a promising and a potential candidate for 5G and beyond wireless networks.

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