Performance of a Coherent QPSK System with an Adaptive Antenna Array at Base Station

Minh-Tuan Le, Van-Su Pham, and Giwan Yoon, *Member, KIMICS*

Abstract**—**In this paper, we present a method to evaluate the BER performance of a coherent QPSK system using an adaptive array to eliminate CCI and demonstrate closed-form expressions for obtaining exact BER of the desired user for the case in which the time delays of all users are equal. The theoretical results are verified by computer simulation under the assumption that Least Mean Square beamforming algorithm is employed.

Index Terms**—**QPSK, MMSE, LMS, Adaptive beamforming algorithm, BER.

I. INTRODUCTION

Smart antennas have been proven to be a very promising technique for enhancing the performance of wireless communication systems [1]-[2]. Besides, a smart antenna has capability of eliminating co-channel interference based on the deference among the DOAs of users. Consequently, there is an increase in the signal-to-interference-plus-noise ratio (SINR) or a reduction in BER for a given signal-to-noise ratio as recognized by the authors in [3]-[4].

In this paper, we analyze the BER performances of a coherent Quadrature Phase Shift Keying (QPSK) system using an adaptive array at base station to combat co-channel interference. The channels are assumed to be Additive White Gaussian Noise (AWGN) and one-path slow flat Rayleigh fading with AWGN. Initially, based on the assumption that the signals of all users reach to the array at the same time, we analytically construct closed-form expressions for the exact BER of the desired user in terms of desired SNR per bit, *i.e.*, the SNR per bit of the desired user, co-channel interference SNRs per bit, *i.e.*, the SNRs per bit of all co-channel interferers, and the DOAs of the users when the minimum mean squared error (MMSE) beamformer is used. After that, the analytical results will be verified by computer simulation. Computer simulation results obtained by using the well-known Least Mean Square (LMS) beamforming algorithm [5] show a very good agreement with analytical results. As the time delays associated with co-channel interferers are different from that of the desired user, computing the exact BER of the desired user in such a case is a very complicated work. Thus, the results for the case in which the time delays of co-channel interferers are uniformly distributed over the range from zero to twice the symbol duration are provided by computer simulation.

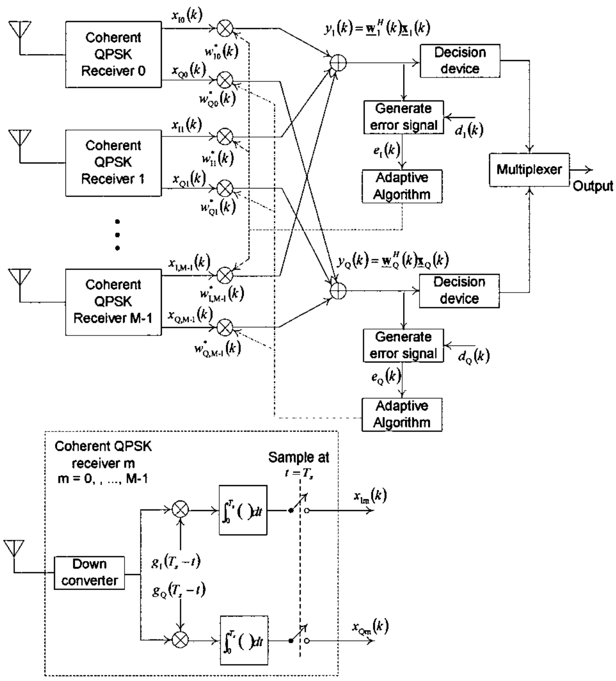

Fig. 1 Coherent QPSK receiver with a smart antenna – model for analyzing BER performance.

II. BIT ERROR RATES OF A COHERENT QPSK SYSTEM WITH A SMART ANTENNA AT BASE STATION

Consider $(K+1)$ users transmitting signals through a slow fading channel to a base station with an array of M elements. A block diagram of a coherent QPSK receiver with a smart antenna is illustrated in **Fig. 1**.

The optimum weight vectors obtain based on the MMSE criterion for both I and Q channels are equal and are of the form:

$$\underline{\mathbf{w}}_o = \zeta \mathbf{R}_{I,uu}^{-1}\underline{\mathbf{a}}(\theta_0) = \zeta \mathbf{R}_{Q,uu}^{-1}\underline{\mathbf{a}}(\theta_0) = \zeta \mathbf{R}_{uu}^{-1}\underline{\mathbf{a}}(\theta_0) \quad (1)$$

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where $\mathbf{R}_{uu} = \sum_{k=1}^{K} \underline{\mathbf{a}}(\theta_k)\underline{\mathbf{a}}^H(\theta_k)E\left[\alpha_k^2\right]E_{sk}/2 + N_0\mathbf{I}$.

A. In AWGN channel

The average BER of the desired user in the coherent QPSK system in AWGN channel is found to be:

$$P_{AWGN}(\gamma_{b0}) \approx \frac{1}{2} erfc\left(\sqrt{\frac{\left|\underline{\mathbf{a}}^H(\theta_0)\mathbf{R'}_{uu}^{-1}\underline{\mathbf{a}}(\theta_0)\right|^2 \gamma_{b0}}{\left[\sum_{k=1}^{K} \left|\underline{\mathbf{a}}^H(\theta_0)\mathbf{R'}_{uu}^{-1}\underline{\mathbf{a}}(\theta_k)\right|^2 \gamma_{bk} + \underline{\mathbf{a}}^H(\theta_0)\left[\mathbf{R'}_{uu}^{-1}\right]^2\underline{\mathbf{a}}(\theta_0)\right]}} \right) \quad (2)$$

where $\mathbf{R'}_{uu} = \sum_{k=1}^{K} \underline{\mathbf{a}}(\theta_k)\underline{\mathbf{a}}^H(\theta_k)\gamma_{bk} + \mathbf{I}$.

B. In flat Rayleigh fading channel

In such kind of channel, the final result for the BER of the desired user in Rayleigh channel is given by:

$$P_{FADING}(\bar{\gamma}_{b0}) = \frac{1}{2}\left(1 - 1/\sqrt{1 + 1/\bar{\eta}_0}\right) \quad (3)$$

where

$$\bar{\eta}_0 = \frac{\left[\underline{\mathbf{a}}^H(\theta_0)\mathbf{R'}_{uu}^{-1}\underline{\mathbf{a}}(\theta_0)\right]^2 \bar{\gamma}_{b0}}{\left[\sum_{k=1}^{K} \left|\underline{\mathbf{a}}^H(\theta_0)\mathbf{R'}_{uu}^{-1}\underline{\mathbf{a}}(\theta_k)\right|^2 \bar{\gamma}_{bk} + \underline{\mathbf{a}}^H(\theta_0)\left[\mathbf{R'}_{uu}^{-1}\right]^2\underline{\mathbf{a}}(\theta_0)\right]} \quad (4)$$

$\mathbf{R'}_{uu} = \sum_{k=1}^{K} \underline{\mathbf{a}}(\theta_k)\underline{\mathbf{a}}^H(\theta_k)\bar{\gamma}_{bk} + \mathbf{I}$, and $\bar{\gamma}_{bk} = E\left[\alpha_k^2\right]\gamma_{bk}$, $k = 0,1,\ldots,K$, is the averaged SNR per bit for the k^{th} user.

III. VERIFICATION OF THEORETICAL RESULTS AND DISCUSSIONS

In this section, the analytical results are verified by computer simulation. Some main simulation parameters are as follows. A uniform linear array with a half-wavelength spacing between adjacent elements is used. The symbol rate is $R_s = 256\,kbauds/s$. The maximum Doppler shift is $f_D = 160Hz$. A pulse-shaping root raised-cosine filter with roll-off factor of 0.5 is used to eliminate ISI. The co-channel interference powers all are equal and are 10dB less than that of the desired signal. The DOAs of all the signal paths are chosen from the set (10°, 25°, -20°, 30°, -25°, 42°, 50°, 29°, 33°, 22°, 36°, 70°, -40°, -35°, -70°). We assume that DOA of the desired signal path is 10°. **Fig.2** and **Fig. 3** illustrate the theoretical results and the simulation results for the QPSK system in AWGN channel and in one-path flat Rayleigh fading channel with AWGN, respectively, for different numbers of elements and users.

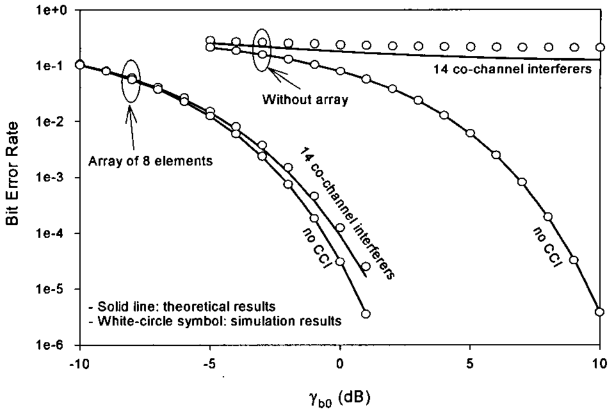

Fig. 2 BER versus SNR per bit of the desired user in the QPSK system - AWGN channel.

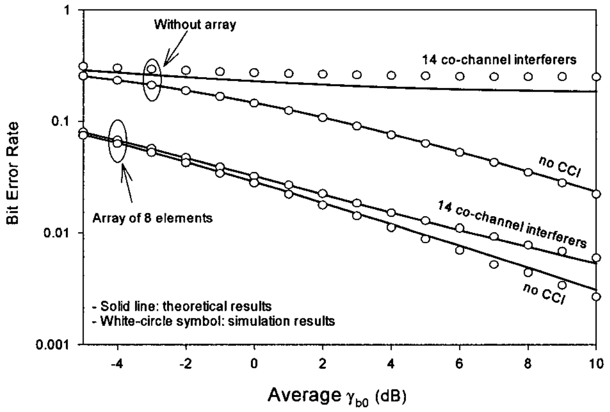

Fig. 3 BER versus SNR per bit of the desired user in the QPSK system – Flat Rayleigh fading channel with AWGN.

As shown in these figures, there is a good agreement between the simulation results and the theoretical ones.

Fig. 4 shows the simulation results for the case all users have the same time delays and the case the time delays of co-channel interferers are uniformly distributed over $(0, 2T_s)$.

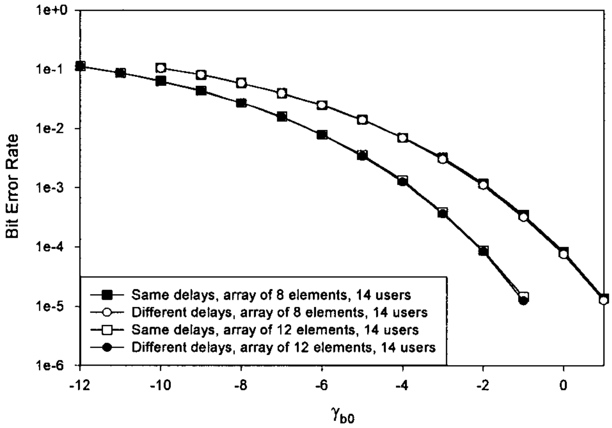

Fig. 4 BERs of the desired user in the QPSK system when the time delays of co-channel interferers are uniformly distributed compared with those when the time delays of all users are equal.

IV. CONCLUSIONS

This paper presents a method to evaluate the BER performance of a coherent QPSK system using an adaptive array to eliminate CCI and demonstrates closed-form expressions for obtaining exact BER of the desired user for the case in which the time delays of all users are equal.

The theoretical results are correct, as confirmed by simulation results, so long as the two most critical assumptions aforementioned above are satisfied. Simulation results also prove that, for the case with arbitrary time delays of the co-channel interferers, the derived closed-form expressions can be used to estimate the BER of the desired user in AWGN channel as well as in Rayleigh fading channel with AWGN.

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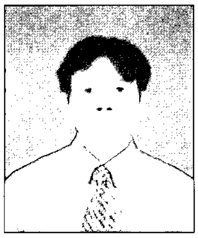

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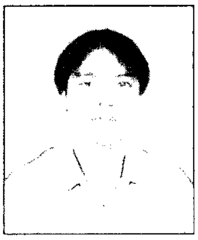

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