EFFECTS OF THE TRANSMISSION CHANNEL ON THE LS-CMA BASED BEAMFORMER IN MOBILE COMMUNICATIONS

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Abstract- **In mobile communications, transmission channel causes significant effects on the signal of mobile users received by the BTS. These changes can degrade the performance of the beamformer. In this paper, undesired effects of the transmission channel on the performance of the LS-CMA based beamformer are investigated both theoretically and through simulations.**

Investigations of this paper show that the effect of transmission channel on the beamformer performance depends on some parameters such as modulation technique used in the transmitter, mobile environment, and etc. But in general, phase error and angular spread have the worst effect on the beamformer performance.

I. INTRODUCTION

Adaptive beamforming is one of the most popular techniques in mobile communications used for increasing the capacity of the mobile networks. Before receiving the signal by the BTS, it passes through the transmission channel. The transmission channel distorts most of the signal parameters. Because, most of the beamforming algorithms use the received signal to update the beamforming weights, undesired effects of the transmission channel on the received signal can degrade the performance of the beamformer.

There are various methods for analyzing effects of the transmission channel on the transmitting signal [1]-[3]. Some former researches investigated the effects of the transmission channel on the beamforming algorithms [4], or on the performance of different detection techniques [5]. Analysis of the effects of the phase and amplitude error on the null depth of the beam power pattern is another subject, which is discussed in [6]. Also, there are some other works in this field which try to make beamforming algorithms resistant to transmission channel or against uncertainties in channel parameters. Linear Constraint-Constant Modulus Algorithm (LC-CMA) [7] is one of these techniques. Although the former works cover a wide range of the subjects about the effects of the transmission channel on the beamforming and detection techniques, but most of these researches use simple models to describe the transmission channel. In these models usually multipath and time delay or phase and amplitude error are considered.

In this paper, the impact of some of the important transmission channel effects such as amplitude and phase error, angular spread, and time delay on the performance of the Least Squares-Constant Modulus Algorithm (LS-CMA) based beamformer [8,9] are investigated both theoretically and by simulation. In this regards, a general signal model which contain most of the channel effects is considered in section II. In section III the LS-CMA beamforming algorithm is discussed. After that the effect of the transmission channel on the beamforming weighs is investigated. Since the signal model established for the received signal by the BTS is a complex model, it is impossible to analyze effects of the channel on the beamformer performance. Therefore, this problem is investigated by simulations in section IV to illustrate effects of the transmission channel on the performance of the LS-CMA based beamformer.

In this paper, it is assumed that beamforming is done in the BTS and for uplink mode. Although in section III a general form is considered for the transmitted signal, but simulations of section IV are based on CDMA signal model.

II. SIGNAL MODEL

In this paper we use Gaussian Wide Sense Stationary Uncorrelated Scattering (GWSSUS) channel model [3] to describe the transmission channel and establishing the signal model based on this channel model. GWSSUS is a statistical channel model which takes some statistical assumptions about the position and other properties of the scatterers into account. It assumes that all scatterers are divided in clusters, which are distributed uniformly between and around the mobile sets and BTS. Also the distribution of the scatterers in each cluster is uniform. These assumptions cause some special probability distributions for different parameters of the signal received by the BTS. These special probability distributions are taken into account in the simulations.

The baseband form of the signal generated by *i*'th mobile user can be written as follows

$$d_i(n) = a_i^d(n) e^{j\varphi_i^d(n)} \tag{1}$$

where $a_i^d(n)$ and $\varphi_i^d(n)$ are the amplitude and phase of the *i*'th user in the *n*'th iteration, respectively. In general $d_i(n)$ can be real or complex. In this paper, a general complex form has been used for $d_i(n)$. Because of using array antenna, the BTS receives a vector of input signals. The baseband form of this vector can be written as

$$\mathbf{x} = \sum_{i=1}^{U} \sum_{p=1}^{P} \alpha_{ip}^e e^{j\varphi_{ip}^e} d_i(n - k_{ip}) \mathbf{a}(\theta_i + \delta_{ip}) + \mathbf{n} \tag{2}$$

where U is the number of users and P is the maximum time delay that can be removed by the receiver *i.e.* P is the number of paths of each user that can be detected by the beamformer. θ_i is the AOA of the LOS ray of the i'th user, δ_{ip} , k_{ip} , $\alpha^e_{ip}-1$, and φ^e_{ip} are the angular spread, time delay, amplitude error, and phase errors of the p'th path of the i'th user respectively, d is the interelement spacing of the antenna array, and λ is the wavelength. Also $\mathbf{n}$ is the impinging noise vector and $\mathbf{a}(\theta)$ is the steering vector for the signal received from direction θ . This vector can be written as fallows

$$\mathbf{a}(\theta)=\begin{bmatrix}1 & e^{j\frac{2\pi d}{\lambda}Sin\theta} & \Lambda & e^{j\frac{2\pi d}{\lambda}(M-1)Sin\theta}\end{bmatrix}. \qquad (3)$$

In the BTS, the desired signal paths that are received by the array antenna with a time delay more than P, have a role like interference signals. Since these signals usually travel very long paths, their power is so small that neglecting them does not make severe error in the model of the signal received by the BTS. Based on the GWSSUS model, amplitude error occurred in the paths of each user have Rician distribution when LOS rays exist and have Rayleigh distribution in non LOS scenarios, phase error is a uniform random variable in the interval [0 2π), time delay has uniform distribution, and angles of arrival of the paths of each user have Gaussian distribution [3].

III. THEORITICAL ANALYSIS

The LS-CMA algorithm [8,9] is one of the most popular beamforming algorithms in mobile communications. This algorithm generates the beamforming weights as follows

$$\mathbf{w}=\mathbf{R}_{xx}^{-1}\mathbf{r}_{xd} \qquad (4)$$

where $\mathbf{R}_{xx}$ and $\mathbf{r}_{xd}$, the autocorrelation matrix and cross correlation vector are calculated as follows

$$\mathbf{R}_{xx}=E[\mathbf{x}(n)\mathbf{x}^H(n)] \qquad (5)$$

and

$$\mathbf{r}_{xd}=E\left[\mathbf{x}(n)\hat{d}^*(n)\right] \qquad (6)$$

where $\mathbf{x}(n)$ and $\hat{d}(n)$ are the input vector and the training signal, respectively. This signal is correlated with the signal of desired user. In order to converge the beamformer to the proper weights, a known signal transmit at the beginning of the signal transmission. After convergence, the training signal is constructed by using the beamformer output. By using the signal model established in 2, the autocorrelation matrix and cross correlation vector are calculated as follows

$$\mathbf{R}'_{xx}=\sigma_s^2\sum_{i=1}^{U}\sum_{p=1}^{P}\rho_i(\theta_{ip})\sigma^2_{e,ip}\mathbf{R}(\theta_{ip})+\mathbf{R}_n \qquad (7)$$

and

$$\mathbf{r}_{xd}=\sigma_s^2\sum_{p\in S}\rho_1(\theta_{1p})\mathbf{a}(\theta_{ip}) \qquad (8)$$

where $\rho_1(\theta)$ is the Probability Density Function (PDF) that describe the angular distribution of the desired signal paths, θ_{ip} is the angle of arrival of the p'th path of the i'th user, $\mathbf{R}(\theta)$ is the correlation matrix correspond with $\mathbf{a}(\theta)$, and S is the set of paths of the desired signal which are correlated with the training signal because of their small time delays.

The above analysis show that angular spread has no significant effect on the autocorrelation matrix but the crass correlation vector is affected by the angular spread, hard. In this case, only some paths of the desired signal which are approximately synchronous with the training signal are used to produce the cross correlation vector. Also, phase error has no effect on autocorrelation matrix. Since this matrix is computed by multiplication of the input signal into its complex conjugate, all elements of the autocorrelation matrix will be real. So the phase error has no effect on this matrix. But this error degrades the beamformer performance by affecting the cross correlation vector. This error destroys both beamforming information and transmitted data. Because of the popularity of the phase modulations and high sensitivity of the beamforming information to the phase error, this error has significant effects on the beamformer performance.

The amplitude error affects the beamformer performance by distorting $\rho_1(\theta)$. Because of angular spread effect, the beamformer can not receive all paths of the desired user. In this case, the beamformer has to compromise between paths of the desired signal to obtain the best paths (paths with higher power). So, any distortion in $\rho_1(\theta)$ decreases the quality of the received signal by decreasing the power of the desired signal received by the beamformer. Of course, the type of modulation technique used in the transmitter has key role in the effect of the transmission channel on the beamformer performance.

IV. SIMULATION RESULS

In the simulations of this section, it is assumed that there are 7 homogeneous antenna elements with λ/2 inter-element spacing in a linear array in the BTS. This antenna receives the signal of one desired user from 0° and two interfering users from ±30°. The phase error has uniform distribution in the interval [0 2π) and the amplitude error has Rician distribution. Note that the transmission channel effects are applied to both desired and interference signals. The transmitted signals used in this section are BPSK signals with length 200 bits which have been spreaded with 32 chips Walsh codes.

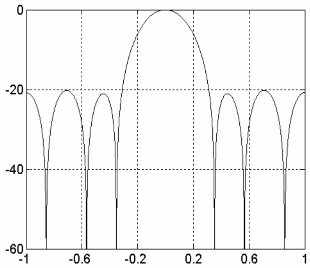

Fig. 2. Beam power pattern in absence of phase and amplitude errors.

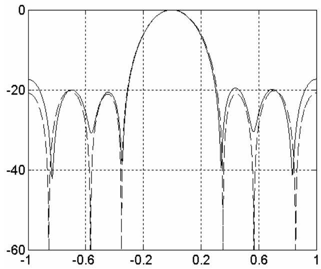

Fig. 3. Beam power pattern in presence of amplitude error.

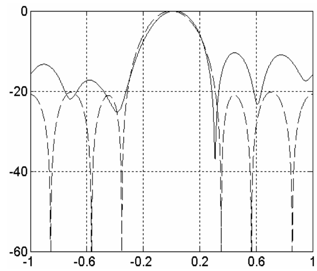

Fig. 4. Beam power pattern in presence of phase error.

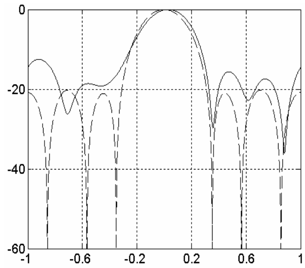

Fig. 5. Beam power pattern in presence of both phase and amplitude errors.

Generally, two sorts of simulations are presented in this section. The first sort shows the effect of phase and amplitude error on the beam power pattern. In order to do these simulations, a simple channel model is considered. The second sort of the simulations represents the impact of some of the most important channel effects such as phase and amplitude error, angular spread, and time delay on the beamformer performance.

Fig. 2 shows the beam power pattern in the case that the phase and amplitude error are equal to zero. Fig's 3 and 4 show the effect of phase and amplitude errors, respectively. As seen in these figures, the amplitude error degrade the nulls depths but the phase error besides distorting angles of nulls, increase the side lobe level. These figures show that the phase error has more significant effects than the amplitude error. Fig. 5 shows the case that both phase and amplitude errors affect the signal. As seen in this figure, in the presence of phase and amplitude errors, the beam power pattern suffers both degradations of the two former cases. In this case decreasing in the side lobe level, distortions in the angles of nulls and decreasing in the nulls depths will occur. The most important point that can be achieved from these figures is that the amplitude and phase error can not distort the main lobe significantly. It is because of using training signal.

In the second sort of the simulations of this paper, by taking a more complex signal and channel model into account, the effect of most important transmission channel effects on the beamformer performance are investigated. There are several parameters such as output signal to noise and interference ratio, Bit Error Rate (BER), and Sample Error Rate (SER) to measure the beamformer performance. BER is the rate of error bits in the despreaded signal and SER is the rate of error samples in the beamformer output and before despreading. Because of using digital signals in mobile communications, BER and SER are better measures for the performance of the beamformer. Among these two parameters, SER is preferred because it only shows the improvements caused by the beamformer. Fig's 6-8 shows the effects of above transmission channel effects on the output SER in different values of input SINR.

Fig. 6 shows the effect of increasing the variation range of the time delay occurred in the paths of the signal of each user on the output SER. For each curve in this figure, time delay is a uniform random variable in the interval mentioned in this figure. The time delay is occurred because of the difference between lengths of the paths of the signal of each user. Increasing the time delay variation degrades the beamformer performance by decreasing the correlation between the training signal and signals of the paths of the desired user. As seen in this figure, increasing the time delay variation range causes the same degradation on the beamformer performance for different values of input SINR's. It shows that it is impossible to mitigate the effect of the time delay by increasing input SINR.

The effect of phase error is represented in Fig. 7. Each curve in this figure is plotted for a special range of the phase error. This figure shows that increasing the range of the phase error variation degrades the beamformer performance significantly. Since the information about the angle of arrival of the paths of each user are stored in the phase of the received signal, the phase error can degrade the beamformer performance severely by distorting the beamforming information. On the other hand, because of high sensitivity of the phase of the signal to the non idealities, phase error can change the position of the symbols in the symbol constellation. In this case the training signal estimated by using the beamformer output has considerable differences with the desired signal. It is clear that the sensitivity of the beamformer performance arise with increasing the order of modulation because increasing the order of modulation cause approaching the symbols positions in the symbol constellation.

Fig. 8 shows the effect of changing the variance of the amplitude error on the output SER. As seen in this figure, the amplitude error has no significant effect on the beamformer performance. It is mainly because the amplitude error changes only the distribution of the amplitude of the paths of each user. Since in these simulations the signal model is generated based on BPSK modulation technique, the amplitude of the desired signal is always constant. So the amplitude error has no significant effect on the beamformer performance. Fig. 9 shows the effect of increasing the angular spread on the output SER. In this figure different ranges of angular spread are tested. As seen in this figure, increase in the angular spread range has

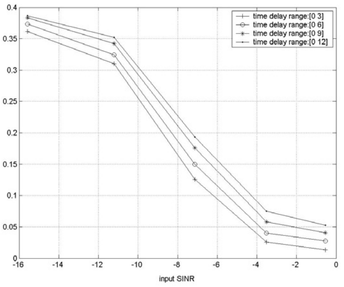

Fig. 6. Effect of changing time delay variation interval on the output SER

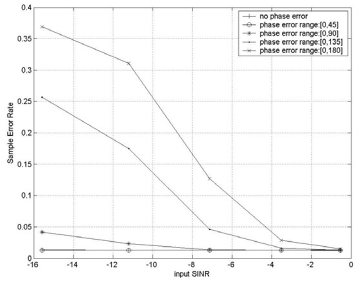

Fig. 6. Effect of changing phase error variation interval on the output SER

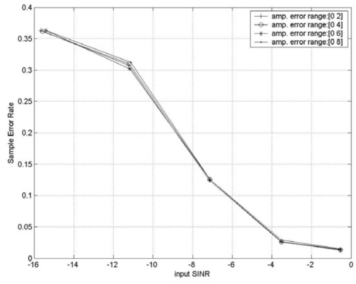

Fig. 8. Effect of changing amplitude error variation interval on the output SER

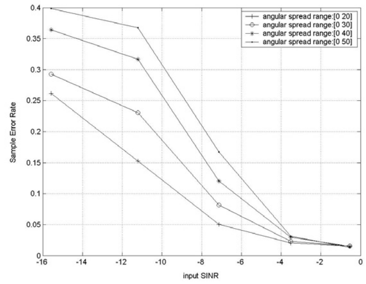

Fig. 9. Effect of changing angular spread interval on the output SER

significant effect on the beamformer performance. This degradation is because of approaching of the angle of arrival of paths of the interferences and undesired signals to the angles of arrival of paths of the desired signal. In this case the beamformer can not produce suitable weights to extract paths of the desired signal from the interferences. This figure also shows that the performance degradations caused by increase in the angular spread range can be suppressed by increasing the input SINR. The effect of angular spread error increases especially in the urban environments.

V. CONCLUSION

In this paper the impact of the most important effects of the transmission channel on the performance of the LS-CMA based beamformer was investigated. The results of our investigations show that the amplitude error affects the beamformer performance by distorting the angular distribution of the desired signal paths but because of using BPSK modulation technique in the transmitter, there are no information in the amplitude of the received signal. So as yields from the simulations, the amplitude error has no effect on the output SER. Some other channel effects like angular spread, phase error and time delay degrade the performance of the beamformer. Angular spread increases the probability of putting paths of the undesired signal near the paths of the desired signal. Increasing the angular spread in urban environments increases the importance of this effect of the transmission channel. Phase shift destroys both beamforming information and transmitted data. Because of increasing the use of phase modulations in mobile communications, this error is one of the most important effects of the transmission channel. Time delay affects the output SER by decreasing the correlation between the desired signal paths and training signal. Therefore, among the non ideal transmission channel effects, angular spread and phase error are the worst.

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