Application of Diversity Technique to the Beamforming System for Mobile Communication

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ABSTRACT

A space diversity technique was applied to the conventional optimal beamforming structure using antenna arrays at the base station receiver in the wireless mobile communication system to get performance enhancement due to interference rejection and fading resistance ability of it. To demonstrate the benefit of proposed system, we derived output signal to interference plus noise ratio (SINR) of combined signal from all sub-array groups considering the fading effects and compared with the beamforming-only system. From the analysis and simulation results, we showed that the proposed system can provide high performance gain under Rayleigh fading channel.

I. Introduction

The beamforming system using adaptive antenna arrays provides high performance gain in many applications. Especially, it can increase the capacity of the wireless communication system such as code division multiple access (CDMA) system by reducing the other user's interferences come from other directions which are different from look direction of desired signal[1]. It is well known that the capacity of CDMA system is limited on the power of other user's interference signal. However, the system performance is depends on not only other user's interferences and noises but also their own signal power fluctuations transmitted through the channel. In wireless mobile communication system, these power fluctuations are characterized as Ricean or Rayleigh fading channel whether the line of sight signal exist or not[2] and they make degradation of the system performance severely compared with the additive white gaussian noise (AWGN) channel since the transmitting signal power sometimes becomes very low with randomly behavior and it makes burst errors when deep fading occurs. To solve this difficult problem, several methods were developed to overcome these kinds of fading channel and one of the most effective methods is to use space diversity technique, which do not require additional transmitting power or bandwidth of the system [2]-[4]. The space diversity system constructs several receiving antennas and demodulates independently at the every antennas.

In this paper, we combined the beamforming and the space diversity system using antenna arrays at the base station side to get interference rejection and fading resistance effect simultaneously. It may be considered that the beamforming using antenna arrays at the receiving part can alleviate the fading effect and it is true to some extent since the beam pattern looks direction of desired signal source and rejects the direction of multipath signal reflected by surrounding objects. However, especially in many cases in the urban areas, the most of these reflections are occurred at the besides of user or mobile stations because high buildings are surrounding them and look direction beam pattern in the beamforming system may encompass the multipath signals of interest at the base station.

There are many channel models describing

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above mechanisms, which are generally accepted, and widely used for the purpose of analysis of wireless communication system[5]. Thus the very short delay spreads compared with the symbol period of transmitting signal caused by above reasons can make frequency flat fading effect[3] and the beamforming system cannot solve or avoid the fading phenomena of received signal completely. Additionally the beamforming system does not guarantee the line-of-sight in wireless communications. Therefore we propose following structure in base station receiver. The antenna arrays in the base station receiver are divided into several sub-array groups and each sub-array group is operating as conventional beamforming system. Finally, all of the output signals from all sub-array groups are combined with maximal ratio combining scheme. One major assumption of this proposing system is that all of the receiving signals incident to the receiving sub-array groups are linearly independent each other and this is generally accepted if the distance between antennas is long enough, at least 10 wavelengths[2]. To analyze the performance of beamforming-diversity combined system, the amplitude and phase variation parameters caused by fading channel are included for deriving the signal to interference plus noise ratio (SINR) expression in both the output of each sub-array and final combined signal output from all sub-array groups. The bit error rate (BER) characteristics were also analyzed through simulation and analysis, and we demonstrated that the proposed system can provide high performance gain under fading channel.

In section II, we describe the structure of proposing beamforming-diversity combined system and derives SINR and BER characteristics at the output of each sub-array and combined output of all sub-array groups. In section III, we show the numerical and simulation results that demonstrate how much performance gain can be achieved when diversity technique is applied to the beamforming system. Section IV concludes the paper.

II. STRUCTURE AND SIGNAL MODEL

Fig. 1 shows the adaptive antenna arrays at the base station in wireless mobile communication system consisting of several sub-array groups and each sub-array group has also antenna arrays. The purpose of constructing each sub-array is to get beamforming effect while the combined signal comes from all sub-array groups has space diversity gain which can improve SINR under fading channel environment.

Consider K uncorrelated signal sources impinge on an array of L omnidirectional sub-array antennas in the M sub-array groups with the direction of arrival (DOA) angle θ_{mk} measured in clockwise direction with respect to the normal direction to the linear equally spaced antenna arrays. The time delay comes from kth signal source at the lth antenna at the mth sub-array group can be represented as

$$\tau_{ml}(\theta_{mk}) = \frac{d}{c}(l-1)sin\theta_{mk} \tag{1}$$

where d is the distance between adjacent antennas within sub-array, c is the speed of light. The phase delay of the received signal at the lth antenna is

$$\begin{aligned}\psi_{ml}(\theta_{mk}) &= 2\pi f_0 \tau_{ml}(\theta_{mk}) \\ &= 2\pi\frac{d}{\lambda}(l-1)sin\theta_{mk}\end{aligned} \tag{2}$$

where f_0 is the carrier frequency of the received signal, and λ is the wavelength of the carrier frequency. Denoting the distance d between adjacent antennas within sub-array should be less than $\lambda/2$ and the distance between sub-array groups must be larger than 10λ at least to insure independence of statistics of fading channel[2].

We assume that fading channel statistics within sub-array for each user are same under above relative short antenna distance compared with the wavelength of transmitting signals. On the other hand, relative long distance between sub-array groups keeps the independence of statistics of fading channel. These assumptions can be regarded as best condition scenario for the purpose of this paper and can simplify this problem.

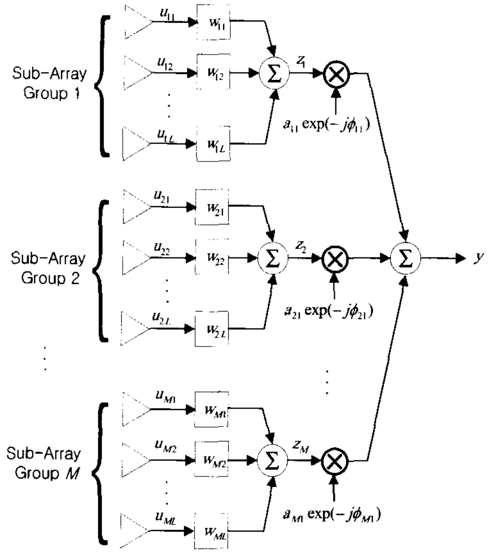

Fig. 1. A base station receiver structure employing adaptive antenna arrays to get beamforming and space diversity effect.

The signal component of induced on the *l*th element due to *k*th signal source at the *m*th sub-array group can be expressed as

$$u_{ml} = \sum_{k=1}^{K} x_k a_{mk} e^{j\phi_{mk}} e^{j\psi_{ml}(\theta_{mk})} + n \tag{3}$$

where x_k is the transmitted complex modulating signal with baseband discrete time domain representation. The structure of the modulating signal reflects the variety of modulation scheme in the communication system. Denoting a_{mk} and $e^{j\phi_{mk}}$ represents instantaneous amplitude variation and phase rotation due to fading channel respectively and the *n* represents AWGN for each antenna element. For the purpose of convenience, we regard the first index signal source as the desired user's signal, therefore (3) can be expressed as

$$\begin{aligned} u_{ml} = {} & x_1 a_{m1} e^{j\phi_{m1}} e^{j\psi_{ml}(\theta_{m1})} \\ & + \sum_{k=2}^{K} x_k a_{mk} e^{j\phi_{mk}} e^{j\psi_{ml}(\theta_{mk})} + n. \end{aligned} \tag{4}$$

The expression is based on the narrow band assumption for array signal processing, which assumes that the bandwidth of the signal is narrow enough and that the array dimensions are small enough for transmitted signal to stay almost constant during τ_{ml} seconds. Additionally, we also assume the slow and frequency flat fading channel that means the fading statistics is almost constant during above time interval[3].

The instantaneous input SINR to the adaptive array at each antenna element can be expressed as

$$\gamma_l = \frac{a_{m1}^2 P_{x_1}}{\sum_{k=2}^{K} a_{mk}^2 P_{x_k} + \sigma_n^2} \tag{5}$$

where $P_{x_k} = x_k{}^2$ and σ_n^2 is AWGN variance which represent signal and background noise power respectively. The numerator in (5) regarded as desired signal power with its own fading amplitude while the first term in denominator in (5) represents interference signal from other user or mobile stations in wireless communication system. The average input SINR at the antenna element can be expressed as

$$\begin{aligned} \bar{\gamma}_l &= E[\gamma_l] \\ &= \frac{\overline{a_{m1}^2}\,\overline{P_{x_1}}}{\sum_{k=2}^{K} \overline{a_{mk}^2}\,\overline{P_{x_k}} + \sigma_n^2} \end{aligned} \tag{6}$$

where $E[\cdot]$ is the expectation operator, $\overline{a_{mk}} = E[a_{mk}]$, and $\overline{P_{x_k}} = E[P_{x_k}]$. The output signal at the *m*th sub-array beamformer is

$$z_m = \sum_{l=1}^{L} w_{ml}^{*} u_{ml} = \mathbf{w}_m^H \mathbf{u}_m \tag{7}$$

where the weight and array input vector are defined by

$$\mathbf{w}_m = [w_{m1}, w_{m2}, \cdots, w_{mL}]^T \tag{8}$$

and

$$\mathbf{u}_m = [u_{m1}, u_{m2}, \cdots, u_{mL}]^T. \tag{9}$$

The superscripts $*$, H, and T in the above equations denote complex conjugate, Hermitian transpose, and transpose of matrix or vector respectively. If $\mathbf{u}_m$ can be modeled as zero mean stationary process, the average output power is

$$\overline{P_{z_m}} = E[z_m z_m^*] = \mathbf{w}_m^H \mathbf{R}_m \mathbf{w}_m \tag{10}$$

where $\mathbf{R}_m$ is the array correlation matrix defined by

$$\mathbf{R}_m = \mathrm{E}[\mathbf{u}_m \mathbf{u}_m^H]\ . \tag{11}$$

In order to derive optimal weights for adaptive beamforming of each sub-array, we define the steering vector associated with the DOA of *k*th source signal at *m*th sub-array as

$$\mathbf{s}_{mk} = [e^{j\psi_{m1}(\theta_{mk})}, e^{j\psi_{m2}(\theta_{mk})}, \cdots, e^{j\psi_{mL}(\theta_{mk})}]^T. \tag{12}$$

The optimal beamforming weights for sub-array are defined by minimizing the average output power of the array while the response of the array measured at the desired direction is constrained to remain constant. This is also known as linearly constrained minimum variance (LCMV) beamformer[6]. Therefore theses weights are the solution of the following optimization problem:

$$\begin{aligned} &\text{minimize} \ \ \mathbf{w}_m^H \mathbf{R}_m \mathbf{w}_m \\ &\text{subject to} \ \ \mathbf{w}_m^H \mathbf{s}_{m1} = 1. \end{aligned} \tag{13}$$

The minimization process minimizes the total noise, including interference and uncorrelated noise. Minimizing the total output noise while maintaining the output signal constant is the same as maximizing the output SINR. The optimal weights solution of (13) is given by [7], [8]

$$\mathbf{w}_{m,opt} = \frac{\mathbf{R}_m^{-1}\mathbf{s}_{m1}}{\mathbf{s}_{m1}^H \mathbf{R}_m^{-1} \mathbf{s}_{m1}}. \tag{14}$$

One of the main purposes of this section is to derive output SINR at each beamformer output and output of beamformer-diversity combined system. Godara has derived output SINR of the optimal beamformer in [9], but he did not considered the fading effect of the channel. In order to derive output SINR of each sub-array group considering of the fading amplitude and phase variations, we can rewrite the correlation matrix (11) by desired signal, interference signal, and noise term as follows

$$\mathbf{R}_m = \overline{\mathrm{a}_{m1}^2}\,\overline{\mathrm{P}_{x1}}\mathbf{s}_{m1}\mathbf{s}_{m1} + \mathbf{R}_{mI} + \sigma_n^2 \mathbf{I} \tag{15}$$

where $\mathbf{R}_{mI}$ is the correlation matrix due to interference signals and it can be expressed as

$$\mathbf{R}_{mI} = \sum_{k=2}^{K} \overline{a_{mk}^2}\,\overline{P_{x_k}}\mathbf{s}_{mk}\mathbf{s}_{mk}{}^H, \tag{16}$$

and $\mathbf{I}$ is the identity matrix. Now we define interference plus noise correlation matrix as

$$\mathbf{R}_{mN} = \mathbf{R}_{mI} + \sigma_n^2 \mathbf{I}. \tag{17}$$

The output power of sub-array (10) including desired signal source, interference, and uncorrelated noise can be expressed using $\mathbf{R}_m$ and $\mathbf{R}_{mN}$ in (15) and (17), it is given by

$$\begin{aligned} \overline{P_{z_m}}(\mathbf{w}_m) &= \mathbf{w}_m^H \mathbf{R}_m \mathbf{w}_m \\ &= \mathbf{w}_m^H [\overline{a_{m1}^2}\,\overline{P_{x_1}}\mathbf{s}_{m1}\mathbf{s}_{m1}^H + \mathbf{R}_{mN}]\mathbf{w}_m. \end{aligned} \tag{18}$$

The first term on the right hand side of (18) represents desired signal source power and the second term represents interference and background noise power at the sub-array output. Dividing (18) into two parts to derive output SINR, the average output power due to desired signal in the sub-array is

$$\overline{P_{z_m,signal}}(\mathbf{w}_m) = \mathbf{w}_m^H \overline{a_{m1}^2}\,\overline{P_{x_1}}\mathbf{s}_{m1}\mathbf{s}_{m1}^H\mathbf{w}_m \tag{19}$$

and by substituting optimal weight vector (14) to the (19), we get

$$\begin{aligned}\overline{P_{z_m,sig}}(\mathbf{w}_{m,opt}) &= \mathbf{w}_{m,opt}^H \overline{a_{m1}^2}\,\overline{P_{x_1}}\mathbf{s}_{m1}\mathbf{s}_{m1}^H\mathbf{w}_{m,opt} \\ &= \overline{a_{m1}^2}\,\overline{P_{x_1}}.\end{aligned} \tag{20}$$

The average output power due to interference is

$$\begin{aligned}\overline{P_{z_m,intf}}(\mathbf{w}_{m,opt}) &= \mathbf{w}_{m,opt}^H\mathbf{R}_{mI}\mathbf{w}_{m,opt} \\ &= \frac{\mathbf{s}_{m1}^H\mathbf{R}_m^{-1}\mathbf{R}_{mI}\mathbf{R}_m^{-1}\mathbf{s}_{m1}}{(\boldsymbol{s}_{m1}^H\boldsymbol{R}_m^{-1}\boldsymbol{s}_{m1})^2},\end{aligned} \tag{21}$$

and similarly, we can express the average output power due to background noise as

$$\begin{aligned}\overline{P_{z_m,noise}}(\mathbf{w}_{m,opt}) &= \sigma_n^2\mathbf{w}_{m,opt}^H\mathbf{w}_{m,opt} \\ &= \sigma_n^2\frac{\mathbf{s}_{m1}^H\mathbf{R}_m^{-1}\mathbf{R}_m^{-1}\mathbf{s}_{m1}}{(\boldsymbol{s}_{m1}^H\boldsymbol{R}_m^{-1}\boldsymbol{s}_{m1})^2}.\end{aligned} \tag{22}$$

We can obtain interference plus background noise power at the sub-array output using (17), (21), and (22) as

$$\begin{aligned}\overline{P_{z_m,intf+noise}} &= \overline{P_{z_m,intf}} + \overline{P_{z_m,noise}} \\ &= \frac{\mathbf{s}_{m1}^H\mathbf{R}_m^{-1}\mathbf{R}_{mN}\mathbf{R}_m^{-1}\mathbf{s}_{m1}}{(\boldsymbol{s}_{m1}^H\boldsymbol{R}_m^{-1}\boldsymbol{s}_{m1})^2}\end{aligned} \tag{23}$$

To derive inverse of input signal correlation matrix in (23), rewriting (15) as

$$\mathbf{R}_m = \overline{\mathrm{a}_{m1}^2}\,\overline{P_{x_1}}\mathbf{s}_{m1}\mathbf{s}_{m1}^H + \mathbf{R}_{mN} \tag{24}$$

and using matrix inversion lemma[5], one obtains

$$\mathbf{R}_m^{-1} = \mathbf{R}_{mN}^{-1} - \frac{\mathbf{R}_{mN}^{-1}\mathbf{s}_{m1}\mathbf{s}_{m1}^H\mathbf{R}_{mN}^{-1}}{1/(\overline{a_{m1}^2}\,\overline{P_{x_1}}) + \mathbf{s}_{m1}^H\mathbf{R}_{mN}^{-1}\mathbf{s}_{m1}} \tag{25}$$

Substituting (25) to the (23), it becomes

$$\overline{P_{z_m,intf+noise}}(\mathbf{w}_{m,opt}) = \frac{1}{\mathbf{s}_{m1}^H\mathbf{R}_{mN}^{-1}\mathbf{s}_{m1}}. \tag{26}$$

The average output SINR of the *m*th sub-array is derived as

$$\begin{aligned}\overline{\gamma_m} &= \frac{\overline{P_{z_m,sig}}(\mathbf{w}_{m,opt})}{\overline{P_{z_m,intf+noise}}(\mathbf{w}_{m,opt})} \\ &= \overline{a_{m1}^2}\,\overline{P_{x1}}\mathbf{s}_{m1}^H\mathbf{R}_{mN}^{-1}\mathbf{s}_{m1}.\end{aligned} \tag{27}$$

Note that the average output SINR of each sub-array beamformer is proportional to the average signal power and fading amplitude, not related on the phase rotation of the channel. Finally, the maximal ratio combined output signal from all sub-arrays is

$$y = \sum_{m=1}^{M} a_{m1}e^{-j\phi_{m1}}z_m \tag{28}$$

and its average output SINR is

$$\overline{\gamma_y} = \sum_{m=1}^{M}\overline{\gamma_m}. \tag{29}$$

The amplitude fluctuations and phase rotations due to Rayleigh fading channel can be estimated using priori known signal such as the pilot signal in wireless communication system. In (28), we assumed that perfect estimation of fading channel and the each path signal from sub-array groups should be compensated with its own perfect estimated values. It is well known that maximal ratio combining scheme is most efficient method for diversity combination technique over the other methods[2], [3].

If one gets the average output SINR, its BER is known as[2]

$$BER_m = \frac{1}{2}\left(1 - \sqrt{\frac{\overline{\gamma_m}}{1+\overline{\gamma_m}}}\right) \tag{30}$$

for non-diversity system. The BER of diversity system is given by[2]

$$\begin{aligned}BER_y = &\frac{1}{2}(1-\beta)^M\sum_{m=1}^{M-1}\binom{M-1+m}{m} \\ &\cdot \frac{1}{2}(1+\beta)^m.\end{aligned} \tag{31}$$

where

$$\beta = \sqrt{\frac{\overline{\gamma_m}}{1+\overline{\gamma_m}}}. \qquad (32)$$

Ⅲ. NUMERICAL AND SIMULATION RESULT

In this section, the performance gain will be discussed when one apply space diversity technique to the beamforming structure in wireless communication system. To get the preliminary result prior to analysis of the beamforming-diversity combined system, we will investigate the performance of beamforming system first.

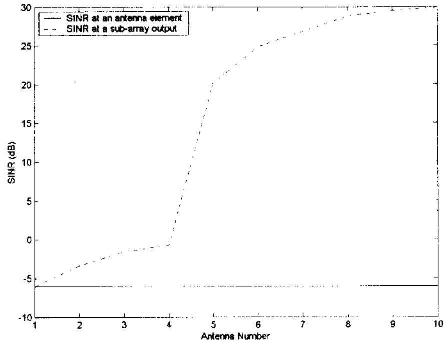

Fig. 2. SINR vs. antenna number of each sub-array group when the number of users is 5, the number of sub-array groups is 4, and AWGN variance of the channel is 0.01.

From the results of (6) and (27), Fig. 2 shows that the SINR trajectory versus the number of antennas when the number of users is 5 and the variance of AWGN of channel is 0.01. Assumption of angle distribution of users is uniform between 85° and 85° measured with respect to the normal direction to the linear array, and look direction of signal for desired user is fixed to 0°. The solid line represents input SINR at the antenna element, dash-dotted line represents output SINR at the each sub-array group. It is not surprising result that the beamforming provides high SINR gain, but if the number of users is greater than the number of antennas, the SINR improvement is sharply decreasing in the beamforming system due to diminishing of degree of freedom.

The mobile communication system is quite different from the signal environment in which adaptive arrays are usually employed. In typical adaptive array application in nonfading environment, at the receiver there are only a few interfering signals, and their power is much greater than that of the desired signals. The adaptive array places nulls in the antenna pattern in the direction of these interferers, greatly suppressing these signals in the array output. Thus the output SINR is, therefore, substantially increased by the adaptive array[10].

In the mobile communication system, on the other hand, at the receiver there can be several interfering signals whose power is close to that of the desired signal, and numerous interfering signals whose power is much less than that of the desired signal. Therefore there are many effective users in mobile communication system and the beamforming-only system cannot provide substantial output SINR improvement under this situation. This limitation of using adaptive array for the mobile communication system can be mitigated by applying beamforming-diversity combined system. In this point of view, the benefit of proposed beamforming-diversity combined system will be discussed as follows.

The average output SINR of beamforming-only and beamforming-diversity combined system according to the total number of antennas is illustrated in Fig. 3, 4, 5, and 6 and these results are derived from the (27) and (29) in section II. In these figures, horizontal axis represent total number of antennas ($M*L$) which are used in the system and the combinations depend on the number of groups (M) and the number of antennas (L) in the each sub-array group are expressed in table I. In every combination pairs, the total number of antennas used in the system is same. The grou p number 1 (M=1) represents beamforming-only system while the group number 2 (M=2) and 4 (M=4) represent beamforming -diversity combined system when the total used group is 2 and 4 respectively. If the total number of antennas is 32 in the table I, as an example, we can compose three candidate pairs which are (M=1, L=32), (M=2, L=16), and (M=4, L=8). The following figures (Fig.3-Fig.6) compare the performance according to those combinations and the number of users.

Fig. 3 shows that the beamforming-only system can provide highest performance gain over the remaining beamforming-diversity combined system when the group number is 2 and 4 even the total number of antennas is same for all of the three cases. This result is based on the fact that the beamforming gain is higher than that of the diversity gain when the number of antenna is greater than the number of users.

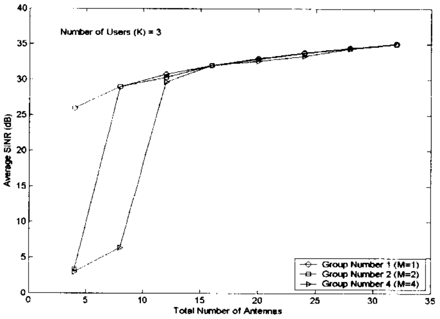

Fig. 3. Average output SINR versus the total number of antennas of the system according to the number of groups. The total number of users is 3.

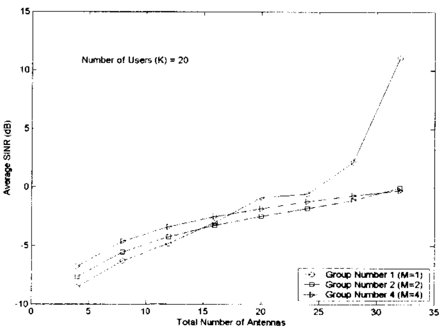

Fig. 4. Average output SINR versus the total number of antennas of the system according to the number of groups. The total number of users is 20.

However if the number of antennas is much greater than that of users in Fig. 3, the diversity gain can approach the performance of the beamforming gain.

Fig. 4, 5, and 6 shows that the performance improvement of the beamforming-only and beamforming-diversity combined system when the number of users is increasing as K = 20, 40, and 60 respectively. In Fig. 4, we can see that the output SINR improvement trajectories between M=1 and M=4 become reversed at the point of the total number of antennas equal 20.

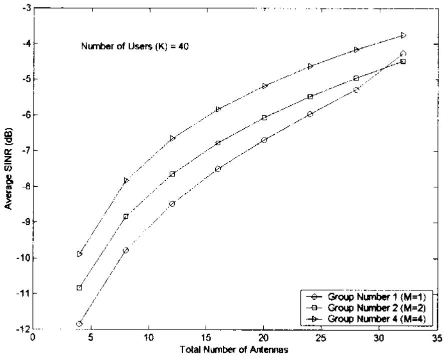

Fig. 5. Average output SINR versus the total number of antennas of the system according to the number of groups. The total number of users is 40.

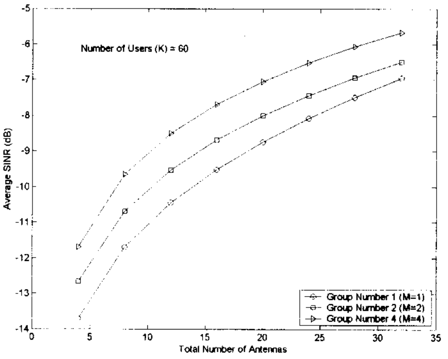

Fig. 6. Average output SINR versus the total number of antennas of the system according to the number of groups. The total number of users is 60.

Table I. The combination pairs consisting of the number of groups (M) and the number of antennas (L) when the total number of antennas is fixed to same in every cases.

M*L	4			8			12			16		
M	1	2	4	1	2	4	1	2	4	1	2	4
L	4	2	1	8	4	2	12	6	3	16	8	4

M*L	20			24			28			32		
M	1	2	4	1	2	4	1	2	4	1	2	4
L	20	10	5	24	12	6	28	14	7	32	16	8

Therefore we can conclude that the beamforming-diversity combined system can provide high performance gain compared with the beamforming-only system when the number of users is greater than that of the number of antennas due to shortage of degree of freedom in the optimal beamforming system using adaptive array.

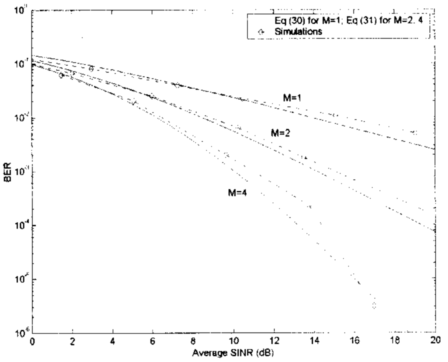

Fig. 7. Performance comparison between beamforming-only and beamforming-diversity combined system.

In most cases the number of users is much greater than the number of antennas which can be feasibly implemented in mobile communications as explained above. In the Fig. 5 and 6, the number of users is always greater than the number of the antennas, the number of users is 40 and 60 respectively, while the maximum number of the antenna is 32 in the system. In this case the proposed method which applying diversity technique to the beamforming system always gives higher performance trajectory and that can improve total output SINR under real mobile communication environment.

Now we will show that the BER performance under fading channel by the results of analysis which derived in section II and computer simulations. The horizontal axis represents the output SINR calculated at the array output while the vertical axis represents BER and this BER performance is illustrated in Fig. 7 for M=1, 2, and 4. In the simulations, the number of users is fixed to 3 where the DOA of desired user's signal is set to 0^o and the DOAs of interferences are set to 56.7^o and 56.7^o respectively for the first sub-array group. Whenever the index of sub-array group is increased, the DOA of each user for the group is also increased by 1^o. The number of antennas within sub-array group is set to 5 and the variance of AWGN of channel is 0.01. Jakes channel model was used for simulations with slow fading characteristic, where we assume that the fading statistics are almost stationary during optimal weight calculation period, a 5 Hz Doppler frequency was used for this reason.

The solid lines imply the results of derived equations (30) and (31) while the dash-dotted lines marked by diamond sign imply the results of simulations in Fig. 7. This figure shows that the beamforming-diversity combined system is very effective compared with the beamforming-only system. Additionally, the derived equations (27) and (29) for SINR estimation of sub-array and combined output of all sub-array groups are quite exact for this system since the BER results of (30) and (31) are match well with the simulation results. Note that these equations are considering the fading effect on the beamforming system. Finally, we can conclude that the performance gain can be achieved if one uses more beamforming groups for diversity combination effect to the fading channel.

Ⅳ. CONCLUSION

In this paper, we proposed beamforming-diversity combined system, which provides high performance gain under Rayleigh fading channel. The diversity technique applied to the conventional optimal beamforming system has benefit of interference rejection and fading resistance simultaneously. To accomplish this purpose, the antenna arrays in the base station receiver are divided into several sub-array groups and the each sub-array group is operated as the conventional optimal beamformer. All of the output signals from all sub-array groups are combined using the maximal ratio combining scheme. To demonstrate the benefit of proposed system, we derived the output SINR of combined signal from the all sub-array groups considering the fading effects.

For the analysis of proposed system, one major assumption was made as follows. That is all of the receiving signals incident to the sub-array groups are linearly independent each other and it is generally accepted if the distance between sub-array groups is long enough. Using the analysis and simulation results, we showed that the proposed beamforming-diversity combined system can provide high performance gain under the Rayleigh fading channel.

We showed that the proposed system can mitigate the degree of freedom problem in real mobile communication field where the number of users is much greater than the number of antennas in most cases. From the analysis in this paper, the diversity gain is much greater than the beamforming gain when the number of users is greater than the number of antennas. Therefore beamforming-diversity combined system can provide both benefits of beamforming and diversity gain regardless of the number of users compared with the beamforming-only system. Finally speaking, the derived output SINR equations are quite exact since the BER curves obtained by simulations were mated well with the analyzed results.

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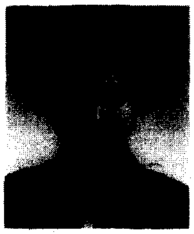

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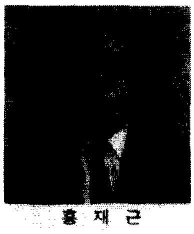

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