Effect of Configuration on Performance of Adaptive Array Antennas for Mobile Terminals

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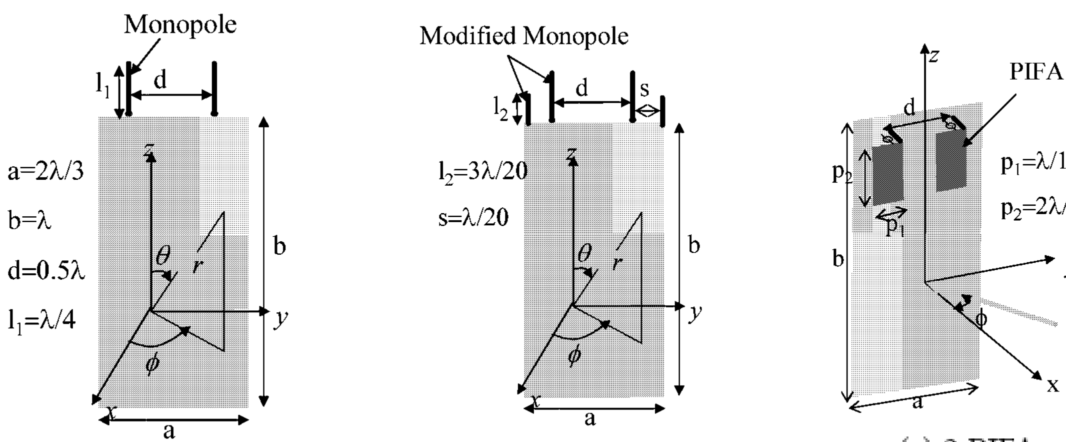
1. Introduction

Adaptive antenna technique has been recognized as one of the key techniques for mobile communications of the next generation with higher data rate and capacity, and the researches on adaptive array antennas (AAA) for small mobile platforms such as wireless LAN cards, PDAs and mobile phones have become more and more active [1]. Many previous researches have been focused on how to remove the effect of the mutual coupling between the array element antennas since the mutual coupling effect has been considered to degrade the capability of adaptive beem steering to the directions of arrival (DOA) of interference waves [1]-[5].

However, it has been shown that even in the presence of the mutual coupling and the nearby scatterers, it is possible to synthesize the beam of array antennas to the DOA of desired waves while direct the null of the adaptive pattern to the DOA of interfering waves if the pattern is synthesized by multiplying the adaptive weights determined by minimum mean square error(MMSE) algorithm with the universal steering vector (USV) [6]. It has also been found that the mutual coupling, which is depended on the configuration of the array antenna and the terminal impedance of each element antenna, may affect the input signal-to-interference-plus-noise ratio (SINR) which has close relation with the output SINR and BER performance of AAAs.

In this research, the performances of several useful adaptive array antennas for mobile terminals are numerically analyzed to investigate the effect of array configuration on the performance of AAA for mobile terminals. These array antennas include 2-element monopole array antenna, and its modified type where the mutual coupling effect between array elements are reduced, as well as 2-element planar inverted-F antenna(PIFA) array antenna. The spatial correlation coefficient of these array antennas to the desired waves and interfering waves and the maximum output SINR to the desired DOA are evaluated by using the USV to show the performance of the AAAs such as output SINR and BER.

2. Configurations of array antennas



(a) 2 Monoploes (b) 2 Modified monoploes (c) 2 PIFAs

Figure 1: Configurations of three kinds of array antennas.

The configuration shown in Fig.1(a) is the array antenna consisting of two monopole antennas. Two monopole antennas have the same length of 0.25λ and are separated by 0.5λ. The configuration shown in Fig.1(b) is the modified type of the monopole array antenna where two parasitic

ISBN: 89-86522-78-0 94460©KEES

element with length of $3\lambda/20$ are added nearby the monopoles with separation of $\lambda/20$. The configuration shown in Fig.1(c) is a two-element PIFA array with a height of 0.1λ. Two PIFAs have the same size of $1/15\lambda \times 2/15\lambda$ and are separated by 0.5λ. These three kinds of array antennas are all mounted on a rectangular conducting plane with size of $2\lambda/3 \times \lambda$, which corresponds to the print board for the mobile terminal. All the antennas are terminated by 50 Ω impedance.

3. Definition of Output SINR

If an array antenna is illuminated by one desired wave E_d from direction of (θ_d, ϕ_d) and one interfering wave E_i from direction of (θ_i, ϕ_i), the output SINR optimized by using MMSE algorithm can be obtained as

$$\mathrm{SINR}^{out} = \left[1 - \frac{P_i}{\sigma^2 + P_i}|\rho_{di}|^2\right] \mathrm{SINR}^{out}_{max}, \tag{1}$$

where the subscript d and i represent parameters related with the desired wave and interfering wave, respectively. P_i represents the received power caused by the interfering wave and σ^2 represents the thermal noise power. ρ_{di} denotes the spatial correlation coefficient between the desired wave and the interfering wave which is evaluated by

$$\rho_{di} = \frac{[A_d]^H [A_i]}{\sqrt{[A_d]^H [A_d]}\sqrt{[A_i]^H [A_i]}}, \tag{2}$$

where $[A_d]$ and $[A_i]$ represent the USV of desired wave and that ofinterfering wave, respectively. The superscript H denotes the conjugate transpose. $\mathrm{SINR}^{out}_{max}$ denotes the upper bound of SINR, which is obtained when only the desired wave exists,

$$\mathrm{SINR}^{out}_{max} = \frac{|P_d|^2}{\sigma^2} [A_d]^H [A_d], \tag{3}$$

where P_d represents the received power caused by the desired wave from direction of (θ_d, ϕ_d). It has been pointed out that $\mathrm{SINR}^{out}_{max}$ can be achieved if and only if there is no interfering wave or the spatial correlation coefficient between the desired wave and the interfering wave is zero[7], and this parameter also corresponds to the maximum active gain at direction of (θ_d, ϕ_d). A_d both in (2) and (3) should be the USV rather than the conventional steering vector(CSV) because the USV can include the mutual coupling and the difference of the element antenna. The efficient way to calculate the USV has been presented in [6].

4. Performance of AAA for mobile terminal

4.1 Spatial correlation coefficient and $SINR^{out}_{max}$

Fig.2 and Fig.3 show ρ_{di} versus ϕ_i in the case of $\phi_d = -20^0$, and $\phi_d = 0^0$, respectively, where both θ_d and θ_i are equal to 90^0. It is found that the spatial correlation coefficient of the PIFA array is mostly the lowest, and the monopole array has smaller spatial correlation coefficient than its modified type.

$\mathrm{SINR}^{out}_{max}$ of these array antennas is shown in Fig.4 where θ is equal to 90^0 and ϕ changes from -90^0 to 90^0. It is found that $\mathrm{SINR}^{out}_{max}$ of the monopole array antenna changes greatly with the horizontal angle ϕ. The $SINR^{out}_{max}$ at direction of $\phi = 0$ for all array antennas achieves the highest value. $SINR^{out}_{max}$ of the 2-element monopole array antenna is the largest one, while that of 2 element PIFA array antenna is the smallest.

S_{12} of three kinds of array antenna is shown in Fig.5. The PIFA array antenna has the weakest mutual coupling. The amplitude of S_{12} of the modified monopole is actually smaller than that of the monopole array antenna. However, it can not be said that the performance of the modified monopole array antenna is always better than that of the monopole array antenna if the spatial correlation coefficient and the maximum active gain are considered as shown in Fig.2– Fig.4.

4.2 BER performance

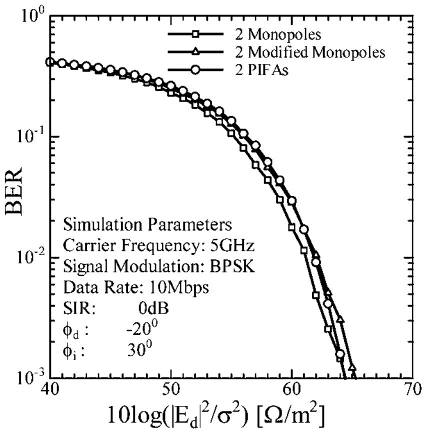


Figure 2: Spatial correlation coefficient($\phi_d = -20^0$).

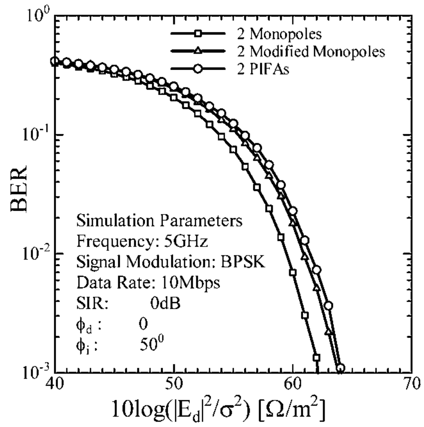


Figure 3: Spatial correlation coefficient($\phi_d = 0$).

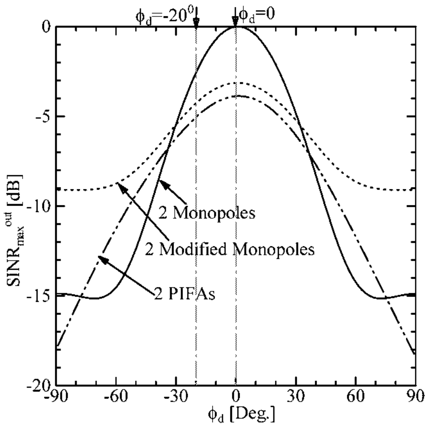


Figure 4: $SINR_{max}^{out}$ of array antennas.

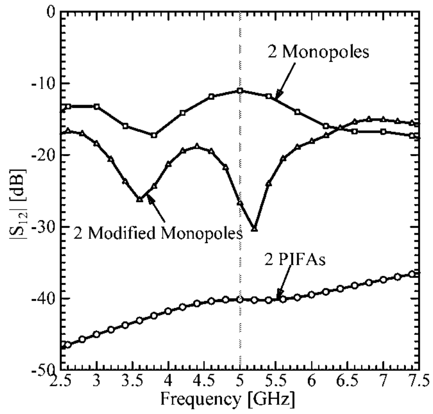


Figure 5: $|S_{21}|$ of array antennas.

Fig.6 shows the BER performances of three kinds of array antennas in the case of desired wave from direction of $\theta_d = 90^0$, $\phi_d = -20^0$ and interfering wave from direction of $\theta_i = 90^0$, $\phi_i = 30^0$. The abscissa in Fig.6 represents the ratio of the electric field amplitude of desired wave to the power of the noise. The ratio of desired wave to interfering wave (SIR) is set to be 0dB. BPSK modulated signal with rate of 10Mbps is used as the incident signal where the carrier frequency is set to be 5GHz. As shown in the graph, it can be found that the BER performances versus the power of the desired wave for three kinds of array antennas are almost the same since the tradeoff the spatial correlation coefficient and the $SINR_{max}^{out}$ makes the effect of array antenna configurations on BER performance is not significant. The spatial correlation coefficients for 2 monopole, 2 modified monopole, 2 PIFA array antennas are -1.88dB, -1.78dB and -7.36dB respectively. The $SINR_{max}^{out}$ at DOA of desired wave are -2.56dB,-4.18dB,-5.07dB respectively where 0dB is the maximum of $SINR_{max}^{out}$ of 2 monopole array antenna.

Fig.7 shows another BER performances of three kinds array antennas where only the incident directions of desired wave and interfering wave are changed to the direction of $\theta_d = 90^0$, $\phi_d = 0$ and the direction of $\theta_i = 90^0$, $\phi_i = 50^0$ respectively. It is found that 2 element monopole antenna has the best performance since it has the largest $SINR_{max}^{out}$ at DOA of $\theta_d = 90^0$, $\phi_d = 0$ which is 3.1dB higher than that of its modified type and 3.8dB higher than that of 2 PIFA array antenna while the spatial correlation coefficients of three kinds of array antennas have similar values (-3.8dB,-2.3dB,-5.8dB).

It is clear now that the performance of an adaptive array can be evaluated by its $SINR_{max}^{out}$ at DOA of desired wave and spatial correlation coefficient between the desired wave and interfering wave which can calculated from the USV or the element pattern when the DOAs of desired wave and interfering waves are known a prior.

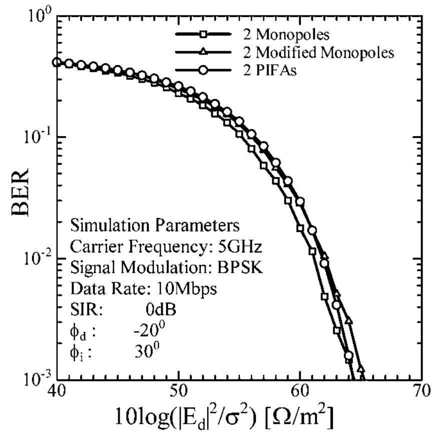


Figure 6: BER performance when $\phi_d = -20^0$, $\phi_i = 30^0$.

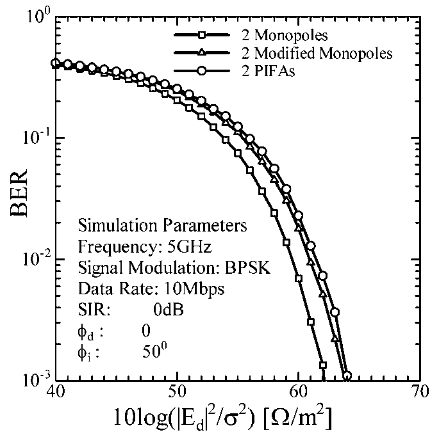


Figure 7: BER performance when $\phi_d = 0$, $\phi_i = 50^0$.

5. Conclusion

The BER performances for 2 element monopole array antenna, 2 element modified monopole array antenna and 2 element PIFA array antenna have been simulated and explained by the spatial correlation coefficient between the desired wave and interfering wave and the $SINR^{out}_{max}$ at DOA of desired wave both of which are calculated by using the USV. It is found that the performances of three kinds of array antennas are almost the same when the desired wave from direction of $\theta_d = 90^0$, $\phi_d = -20^0$ and interfering wave from direction of $\theta_i = 90^0$, $\phi_i = 30^0$, but the performance of 2 monopoles array antenna is better than the others when the desired wave from direction of $\theta_d = 90^0$, $\phi_d = 0^0$ and interfering wave from direction of $\theta_i = 90^0$, $\phi_i = 50^0$. It can be said that the performance of AAA depends on the configuration of array antenna and is the tradeoff between the $SINR^{out}_{max}$ and the spatial correlation coefficient. The $SINR^{out}_{max}$ represents the receiving capability of AAA, while the spatial correlation coefficient represents the nulling capability of AAA. Since the effect of mutual coupling on both two parameters depends on the DOA of incident waves, so it is difficult to say mutual coupling always degrade the performance of an AAA.

The evaluation of the adaptive array performance statistically which is subjected to the knowledge of distributions of the desired wave and interference waves will be our next study.

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