POS1-11

Effect of Element Spacing on Performance of Adaptive Array Antenna System in Indoor Environment

Q. Yuan [1], Y. Takeda [2], Q. Chen [2], K. Sawaya [2], E. Kudoh [2], F. Adachi [2]
[1] Intelligent Cosmos Research Institute, Sendai, 989-3204 Japan
[2] Tohoku University, Sendai, 980-8579 Japan

1. Intruduction

Adaptive array antenna(AAA) 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 antenna for small mobile platforms such as wireless LAN cards, PDAs and mobile phones have become more and more active [1]. AAA system constitutes a multidiscipline area, closely correlated with the advancing interactions between electromagnetic and digital signal processing. The effect of array antenna configuration including mutual coupling on performance of AAA primly belongs to the electromagnetic discipline, and has been researched steadily in recent years [1]- [5].

In [5], it has been found that the mutual coupling affects the antenna gain, but doesn't affect the gain obtained from adaptive processing. That means even in the presence of the mutual coupling and the nearby scatters, it is possible to synthesize the beam of array antenna to the direction of arrival (DOA) of desired wave while the nulls of the adaptive pattern to the DOAs of interfering waves if the pattern is synthesized by multiplying the adaptive weights with the universal steering vector (USV). The effect of the mutual coupling on the output SINR of the adaptive array antenna system is resulted from the effect of on the input SINR of array antenna.

In this paper, a 4-channel wide-band code division access (W-CDMA) receiver is developed to evaluate the performance of AAA system when the element spacing of received array antenna is changed. The indoor environment is an office with desks and chairs, having multipath for incident waves. Further, the mean effective gain(MEG) which consider both the environment and the array element pattern is calculated to explain the effect of array spacing on the performance of array antenna in indoor environment.

2. System Configuration of W-CDMA Receiver

The configuration of the W-CDMA receiver is shown in Fig.1. There are 4 RF branches with SMA input ports to connect 4 receiving antennas. Each RF branch consists of a low noise amplifier and a mixer to convert RF signal at 2.452 GHz to IF signal at 15.36 MHz. In the baseband circuit, the IF signal is over-sampled at a clock of 61.44 MHz and converted into digital data by a 14-bit A-D converter(ADC). The baseband signal is received by a digital demodulator and a correlator. The adaptive control is carried out in digital signal processor 2 (DSP2) and its algorithm can be modified very easily. In this paper, the normalized least mean square(N-LMS) is selected as the adaptive algorithm and the pilot symbol for each downlink slot of W-CDMA DPCH is used as the reference signal for N-LMS algorithm. The synthesized output after adaptive control will be finally obtained in the field programmable gate array (FPGA).

4-monopole array antenna with large metal ground plane shown in Fig.2 is used as the receiving array antenna. The purpose of using large metal ground plane is to alleviate the influences by the connecting cables, while still keeps the radiation properties very similar to that of dipole array antenna. The array spacing is adjustable by changing the connecting position between the monopole element and the metal ground plane.

ISBN: 978-4-88552-223-9 C3055©IEICE

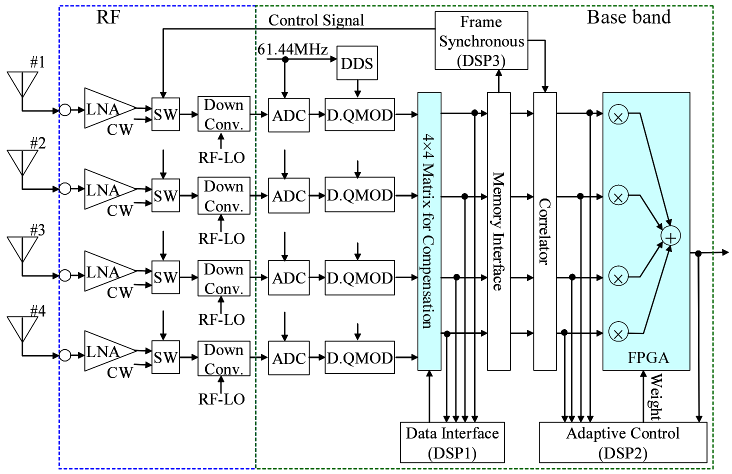

Figure 1: W-CDMA system.

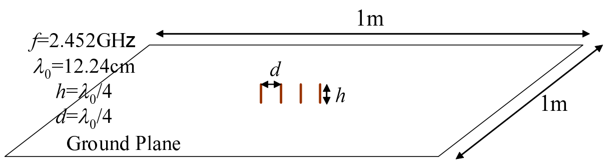

Figure 2: Receiving Array Antenna.

3. Maximum SINR and MEG

The Maximum SINR of AAA system is defined as

$$\mathrm{SINR}_{max}^{out} = \frac{\Gamma_d}{\sigma^2}\left[A(\theta_d,\phi_d)\right]^H\left[A(\theta_d,\phi_d)\right]. \tag{1}$$

where $\frac{\Gamma_d}{\sigma^2}$ represents the ratio of desired signal to noise(SNR), $A(\theta_d,\phi_d)$ represents the array element pattern or USV at DOA of desired wave, the superscript H denotes the complex conjugate. The difference of (1) from the definition in [2] is using the USV instead of the conventional steering vector(CSV) which doesn't include the mutual coupling between array elements.

From (1), it can be found that the upper bound of SINR of AAA system is dominated by the array element pattern and the SNR of desired wave, but has no relation with the parameters of interference waves such as the number, the direction and the power. The Maximum SINRs of 4-dipole array antenna with different array spacing versus the azimuth angle are compared in Fig. 3. $\mathrm{SINR}_{max}^{out}$ of array antenna with small element spacing is not always smaller than that with large element spacing, depending on the DOA of the desired wave. If the DOA of desired wave can be fixed in the environment where an AAA system is applied, $\mathrm{SINR}_{max}^{out}$ is a very useful parameter to evaluate which array antenna performs much better than the other. But for most practical situations, like multipath environment where the direction and polarization of desired wave usually change rapidly with time, therefore it is very difficult to use $\mathrm{SINR}_{max}^{out}$ to evaluate which array antenna performs better. Hence, it is required a statistical approach to evaluate the performance of an AAA system.

One parameter called MEG proposed by Taga [6] meets the above requirement since MEG is the parameter which can combine the effects of multipath in an indoor environment and the free-space antenna radiation pattern. MEG is defined as

$$G_e = \int_0^{2\pi}\int_0^{\pi}\left[\frac{XPR}{XPR+1}G_\theta(\theta,\phi)P_\theta(\theta,\phi) + \frac{1}{XPR+1}G_\phi(\theta,\phi)P_\phi(\theta,\phi)\right] sin\theta d\theta d\phi \tag{2}$$

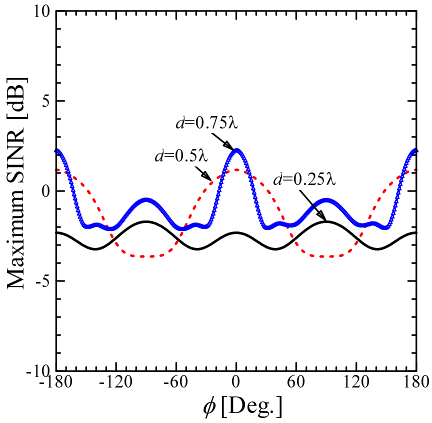

Fig.3 $\mathrm{SINR}_{max}^{out}$ of 4-dipole Array Antenna.

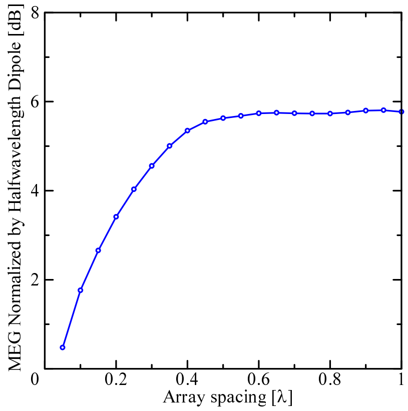

Fig.4 MEG of 4-dipole Array Antenna

where $G_\theta(\theta, \phi)$ and $G_\phi(\theta, \phi)$ are the elevation θ and azimuth ϕ components of the antenna power gain pattern, and $P_\theta(\theta, \phi)$ and $P_\phi(\theta, \phi)$ are the θ and ϕ components of the angular distribution function of incoming plane waves, respectively. *XPR* is the cross-polarization power ratio of the incoming waves. The MEG formulation in (2) requires the knowledge of the angular distribution and *XPR* of the incident waves, both of them are statistical parameter and depends on the environment. In our measurement, the cross polarizations of the transmitting antenna and receiving array antenna are very weak, so the *XPR* and $G_\phi(\theta, \phi)$ are supposed to be 0. Further, since the orientation of receiving array antenna is kept in vertical position, only $G_\theta(\theta = 90^0, \phi)$ needs to be considered and at the same time the angular distribution $P_\theta(\theta = 90^0, \phi)$ can be assumed to be uniform, then the MEG in (2) can be simplified as

$$G_e = \int_0^{2\pi} G_\theta(\theta = 90^0, \phi) P_\theta(\theta = 90^0, \phi) d\phi. \quad (3)$$

The MEGs calculated by using (3) are shown in Fig. 4 where the MEG is normalized by the half-wavelength dipole antenna. It can be observed that the MEG when the array spacing is over than 0.5λ is greater than that when the array spacing is 0.25λ by 4dB, approaching the limitation of 6dB.

4. BER measurement in indoor environment

The BER measurement is performed in a indoor LOS environment—a $9m \times 7m$ meeting room with tables and chairs as shown in Fig. 5. The desired wave and the interference wave generated by vector signal generators are W-CDMA modulated signals whose data formats are shown in detail in Table 1. Every BER is calculated in real time from 100,000 bits of sample data in the FPGA. The BER measurement is conducted by fixing the transmitting antennas and turning the receiving array antenna along azimuth angle ϕ with every 20^0 step. Moreover, the position of receiving array antenna is changed from position A to position F. Therefore the receiving array antenna has 108 positions in BER measurement for each array antenna with different array spacing.

	Desired Wave	Interference
Spread Factor	256	128
Symbol Rate	15 ksps	30 ksps
Spread Code	0	8
data	PN9	Random

Table 1: Specifications of desired wave and interference

The outage probabilities when BER is less than 10^3 versus SIR are shown in Fig. 6. Compared with the single monopole antenna without AAA technique, the improvement when outage probability is 0.5 is achieved by 6dB if the 4-monopole adaptive array with 0.25λ spacing is used, and 8dB if the 4-monopole

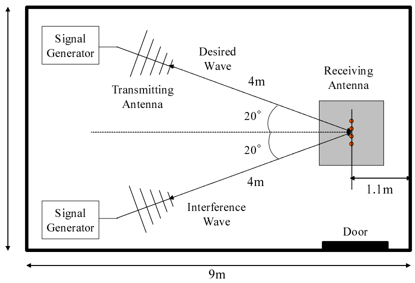

Fig. 5 BER Measurement System.

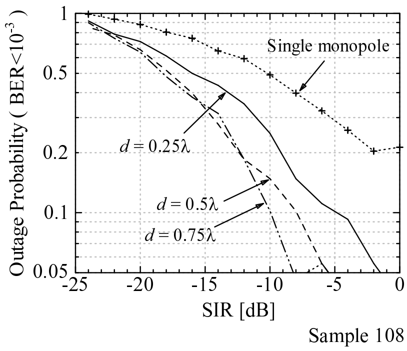

Fig.6 Outage Probability of BER

adaptive array with 0.5λ spacing or 0.75λ spacing is used. The above results demonstrate that the BER performance using adaptive array antenna technique is much better than that using single antenna, again illustrating the validity of the AAA technique in LOS environment.

Actually, the performance depends on the array element spacing—one parameter related with the array configuration. The performance of 4-monopole array antenna with 0.25λ spacing is worse than that of array antenna with larger element spacing such as case of 0.5λ or case of 0.75λ, but difference between the performance of 4-monopole array antenna with 0.5λ spacing and that of array antenna with 0.75λ spacing is very small. The MEG shown in Fig. 4 gives the appropriate explanations of the effect of the array element spacing on BER performance of our adaptive array antenna system.

5. Conclusion

A 4-channel wide-band code division access (W-CDMA) receiver has been developed to evaluate the received array antenna with different array spacing in the indoor LOS environment. The MEG which considers both the environment and the array element pattern has been calculated, and it has been used to explain the effect of array spacing on the performance of array antenna in indoor environments appropriately. The BER performance measured in our W-CDMA AAA system has demonstrated that it can be improved by using the AAA technique greatly, and further demonstrated that the higher MEG of array antenna can offer better BER performance.

References

[1] Gaurav G. Joshi, Carl B. Dietrich, Jr., Warren L. Stutzman, ”Adaptive Beamforming Measurement Using Four-Element Portable and Mobile Arrays,” *IEEE Trans. Antennas Propagat.*, Vol.AP-53, No.12, pp. 4065-4072, Dec. 2005.

[2] HENG-CHENG LIN, ”Spatial Correlation in Adaptive Arrays,” *IEEE Trans. Antennas Propagat.*, Vol.AP-30, No.2, pp. 212-223, March 1982.

[3] I. J. Gupta and A. A. Ksienski, ”Effect of mutual coupling on the performance of adaptive arrays,” *IEEE Trans. Antennas Propagat.*, Vol.AP-31, No.5, pp. 785-791, Sept. 1983.

[4] R. S. Adve and T. K. Sarkar, ”Compensation for the effects of mutual coupling on direct data domain adaptive algorithms,” *IEEE Trans. Antennas Propagat.*, Vol.AP-48, No.1, pp. 86-94, Jan. 2000.

[5] Q. Yuan, Q. Chen and K. Sawaya, ”Performance of Adaptive Array Antenna with Arbitrary Geometry in the Presence of Mutual Coupling,” *IEEE Trans. Antennas Propagat.*, Vol. 54, No. 7, pp. 1991-1996, July 2006.

[6] T. Taga, ”Analysis for mean effective gain of mobile antenna in land radio environments,” *IEEE Trans. Veh. Tech.*, Vol. 39, No. 2 117-131, May 1990.