PROCEEDINGS OF ISAP2005, SEOUL, KOREA

Performance Comparison of Omni-directional- and Directional-Element Adaptive Array Antenna for OFDM Mobile Reception of Digital Terrestrial Television

Pubudu Sampath WIJESENA and Yoshio KARASAWA
Department of Electronic Engineering, The University of Electro-Communications,
1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan
E-mail: pubudu@radio3.ee.uec.ac.jp

1. Introduction

Reception of terrestrial digital television (DTTV) broadcasting in vehicles has become a new research interest with the introduction of DTTV in Japan. Mainly various types of adaptive array antenna have been considered in order to overcome frequency-selective fading and Doppler frequency spread, which are the main problems in OFDM mobile reception [1-3]. Moreover, considering the outward appearance, installing antennas on windows, instead of the roof of vehicles has attracted more attention though it restricts the array elements to directional ones. This paper evaluates the mobile receiving quality of DTTV of Post-FFT-type OFDM adaptive array antenna consisting of omni-directional as well as directional elements. Simulation results confirm that similar performance to omni-directional-element adaptive array antenna can be achieved with the use of directional-element adaptive array antenna. Moreover, the paper shows that remarkable performance improvement can be achieved in directional-element adaptive array antenna mobile reception by the application of Doppler despreading [1]. The paper also proposes allocating directional elements on the front and the rear sides of the vehicle instead of the left and right sides, when using two-directional-element adaptive array antenna.

2. Array Configuration and Adaptive Algorithm

Considering the recent trend of installing antennas on windows instead of the roof, the antenna elements are allocated in four sides of the vehicle as shown in Fig.1, where l and w denote the inter-element spacing between element 1 and 3, and 2 and 4, respectively. It should be noted that the DOA of receiving signals is measured referring the moving direction of the vehicle. Omni-directional as well as directional elements are considered as elements of the adaptive array antenna. Directional elements receive signals only from -90° to 90° and two types of amplitude characteristics are evaluated. One, receiving signals with equal gain irrelevant to the DOA and the other with cosine amplitude characteristic which are referred as equal-gain and cosine-gain elements, respectively in the later part of the paper. The radiation pattern of each element is illustrated in Fig.2 (a). The received signals of elements are combined using a Post-FFT-type maximal ratio combiner (MRC).

2.1 Omni-directional-Element Adaptive Array Antenna

Four omni-directional elements are used in the adaptive array antenna as illustrated in Fig.2 (b). The received signal of Omni-directional element adaptive array antenna is given by

$$\mathbf{R}_{OMNI} = \sum_{i=1}^{I} a_i \left[\exp(j2\frac{\pi}{\lambda}\frac{l}{2}\cos\theta_i), \exp(j2\frac{\pi}{\lambda}\frac{w}{2}\sin\theta_i), \exp(-j2\frac{\pi}{\lambda}\frac{l}{2}\cos\theta_i), \exp(-j2\frac{\pi}{\lambda}\frac{w}{2}\sin\theta_i) \right]^T \quad (1)$$

where I, λ, θ_i and a_i denote the number of multipath signals, wavelength of the DTTV signal, incident direction of the i^{th} multipath and the complex amplitude of the i^{th} multipath, respectively. The center of the antenna array is being used as the reference point when calculating the received signal of each element.

2.2 Directional-Element Adaptive Array Antenna

The equal-gain-element and cosine-gain-element adaptive antennas are shown in Fig.2 (c) and Fig.2 (d), respectively. The received signal of directional element adaptive array antenna is given by

ISBN: 89-86522-78-0 94460©KEES

$$\mathbf{R}_{DIR} = \sum_{i=1}^{I}\left[a_i^1.\exp(j2\frac{\pi}{\lambda}\frac{l}{2}\cos\theta_i), a_i^2.\exp(j2\frac{\pi}{\lambda}\frac{w}{2}\sin\theta_i), a_i^3.\exp(-j2\frac{\pi}{\lambda}\frac{l}{2}\cos\theta_i), a_i^4.\exp(-j2\frac{\pi}{\lambda}\frac{w}{2}\sin\theta_i)\right]^T \qquad (2)$$

where a_i^k for equal gain element adaptive array antenna is given by

$$a_i^1 = \begin{cases}\sqrt{2}a_i & -90^\circ < \theta_i < 90^\circ \\ 0 & else\end{cases}, \quad a_i^2 = \begin{cases}\sqrt{2}a_i & 0^\circ < \theta_i < 180^\circ \\ 0 & else\end{cases}, \quad a_i^3 = \begin{cases}\sqrt{2}a_i & 90^\circ < \theta_i < 270^\circ \\ 0 & else\end{cases}, \quad a_i^4 = \begin{cases}\sqrt{2}a_i & 180^\circ < \theta_i < 360^\circ \\ 0 & else\end{cases} \qquad (3)$$

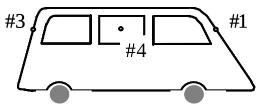
and that for cosine gain element adaptive array antenna is given by

$$a_i^1 = \begin{cases}2a_i\cos(\theta_i) & -90^\circ < \theta_i < 90^\circ \\ 0 & else\end{cases}, \quad a_i^2 = \begin{cases}2a_i\sin(\theta_i) & 0^\circ < \theta_i < 180^\circ \\ 0 & else\end{cases},$$
$$a_i^3 = \begin{cases}2a_i\cos(\pi-\theta_i) & 90^\circ < \theta_i < 270^\circ \\ 0 & else\end{cases}, \quad a_i^4 = \begin{cases}2a_i\sin(\pi-\theta_i) & 180^\circ < \theta_i < 360^\circ \\ 0 & else\end{cases} \qquad (4)$$

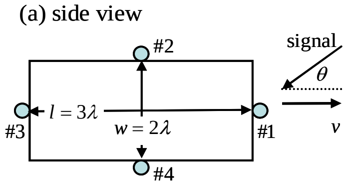
It should be noted that the radiation pattern of each element has normalized by

$$\int_{-\pi}^{\pi} a^2(\theta)\cdot d\theta = 2\pi \qquad (5)$$

where, $a(\theta)$ denotes the amplitude radiation pattern.



(a) side view



(b) top view

Fig.1 antenna installment

2.2.1 Despreading Doppler Frequency Shift

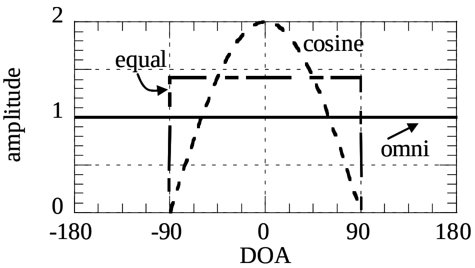
Figure 3 illustrates the possible Doppler spread of the received signal of each element of directional-element adaptive array. Here f_D denotes the maximum Doppler frequency shift. This suggests the application of despreading Doppler frequency spread that introduced in [1] for the element 1 and 3, since the average Doppler frequency shift for them is not zero. Doppler despread signal of i^{th} element is given by

$$\overline{R_{DIR}^i}(t) = R_{DIR}^i(t)\cdot\exp(-j2\pi\Delta f_i), \quad i = 1,3 \qquad (6)$$

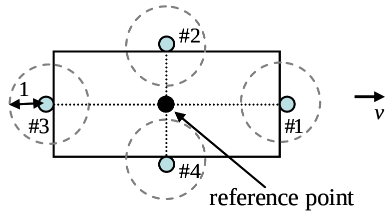
where, R_{DIR}^i and Δf_i denote the received signal of i^{th} element of directional adaptive array and the degree of Doppler despreading, respectively. On the other hand element 2 and 4, which have zero average Doppler frequency shift, cannot be despread.

2.3 Maximal Ratio Combiner

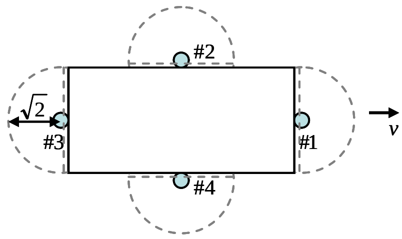
A Post-FFT-type maximal ratio combiner is used to combine the element signals of adaptive array



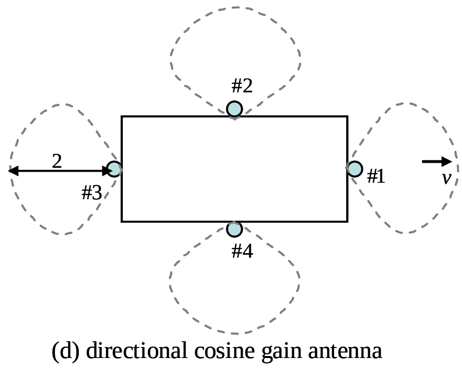
(a) radiation pattern of each element



(b) omni-directional antenna



(c) directional equal gain antenna



(d) directional cosine gain antenna

Fig.2 adaptive array antenna

antenna as discussed in [1]. Firstly, the correlation matrix among the received signals of array elements, $\mathbf{R}_{xx}^{(k)}(t)$, is calculated by taking the sliding average of past 5 samples. Then maximal ratio combining (MRC) is carried out by using the eigenvector $\mathbf{e}_{\max}^{(k)}(t)$, for the maximum eigenvalue $\lambda_{\max}^{(k)}(t)$, of $\mathbf{R}_{xx}^{(k)}(t)$ as the weight vector for the k^{th} sub-channel.

3. Propagation Environment and Assumed OFDM Scheme

3.1 Propagation Environment

A propagation environment with 40 multipath signals with exponential power delay profile is assumed. When emerging multipaths, firstly, the power of the i^{th} multipath is set by

$$P_i = P_{MIN} + (P_{MAX} - P_{MIN}) \cdot \frac{N_{multi} - i}{N_{multi} - 1} \quad [dB] \qquad (7)$$

where, P_{MAX} and P_{MIN} denote the power of the first and the last multipath in dB, respectively. N_{multi} stands for the number of multipaths. The total received power is set to 0dB. The delayed time of i^{th} multipath is set by

$$D_i = \left[\mathrm{int}eger\left(\frac{N_{GI}}{N_{multi}} \cdot i\right) \right] \cdot T \qquad (8)$$

distributing all the multipaths within the guard interval where, T and N_{GI} denote QPSK symbol period and the guard interval normalized by T, respectively. The DOAs of multipath signals are set randomly ranging from 0° to 360°. The assumed propagation environment is shown in Fig.4.

3.2 Assumed OFDM Scheme

Parameters of the assumed OFDM system are given in Table 1. System performance is evaluated by bit error rate (BER) which is averaged over one million bits.

4. Performance Evaluation

Simulations were carried out to optimize the degree of Doppler despreading for cosine-gain and equal-gain elements as well as to evaluate the performances of omni-directional-element and directional-element adaptive array antenna. A result for single antenna (omni-directional antenna) is also presented as a reference.

4.1 Optimizing the despreading factor

Figure 5 illustrates the result of Doppler despreading effect as a function of despreading factor defined by $|\Delta f|/f_D$ to identify the most suitable value of the factor. Result shows that the optimum value lies in $\Delta f \approx \pm f_D/2$ for equal-gain-directional elements and $\Delta f \approx \pm f_D$ for cosine-gain-directional elements. Hereafter we use the above value for simulation.

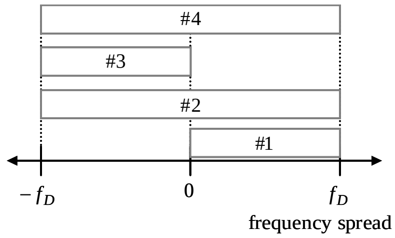


Fig.3 Frequency spread of each element

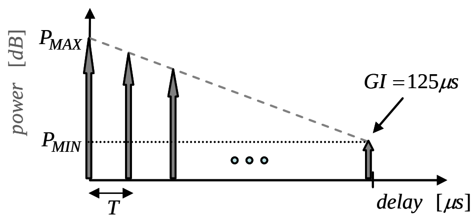


Fig.4 propagation environment
(A discrete type exponential delay profile)

Table 1 system parameter

Number of bits transmitted	1,000,000
Number of sub-carriers (N)	256
Symbol period (without GI) ($T_s = 256 \times T$)	1 ms
Modulation system	DQPSK
Guard interval (GI)	$32T$ ($125\mu s$)
Number of elements	2,4
Element spacing (l)	3λ ($1.5m@600MHz$)
Element spacing (w)	2λ ($1.0m@600MHz$)

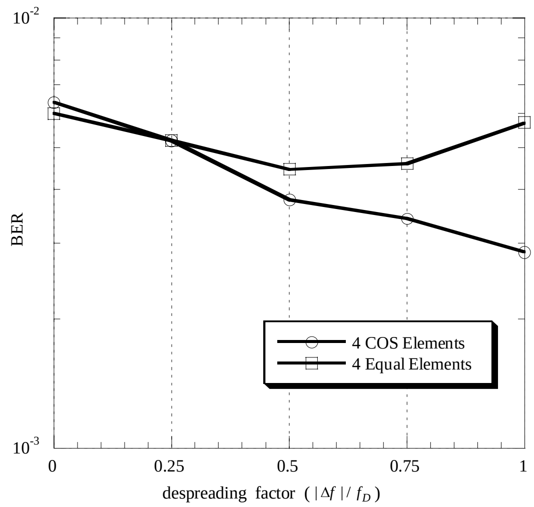


Fig.5 Doppler despreading effect
(SNR=30dB, $f_D T_s = 0.03$)

4.2 Four-Element Adaptive Array

Figure 6 illustrates the BER characteristic as a function of signal-to-noise ratio (SNR). In this case, simulation was done at $f_d T_s = 0$. Result shows that each adaptive array antenna gives similar performance with the absence of Doppler frequency spread.

The characteristic of BER as a function of Doppler frequency spread is illustrated in Fig.7, where w.DD. and w.o.DD. refer to with and without despreading Doppler spread, respectively. The simulation is done under SNR of 40dB. Result confirms that better performance can be obtained by means of the Doppler despreading. Particularly cosine-gain-element adaptive array antenna gives the best performance under severe Doppler spreading environment.

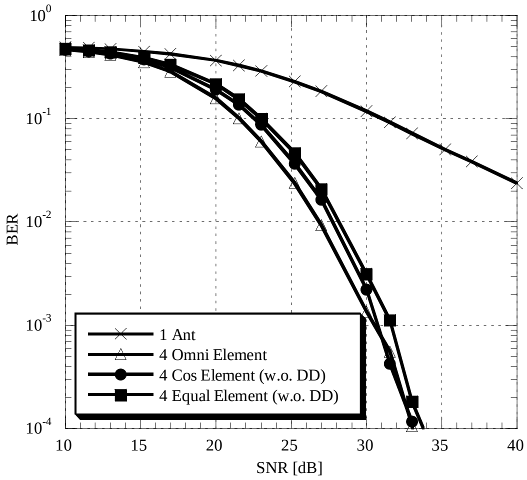


Fig.6 BER vs. SNR ($f_d T_s = 0$)

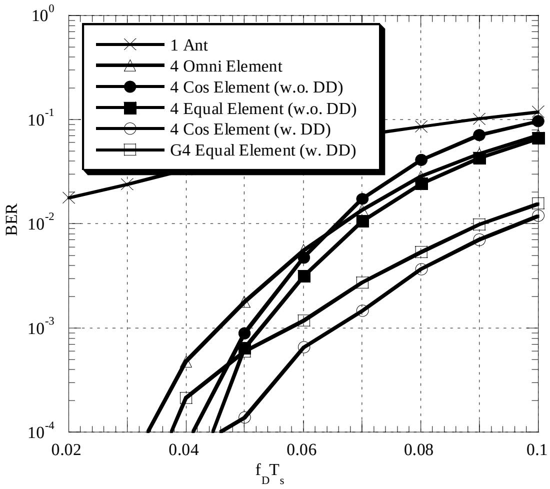


Fig.7 BER vs. Doppler spread (SNR=40dB)

4.3 Two-Element Adaptive Array

Figure 8 illustrates the BER characteristic for 2-directional-element adaptive array antenna. Results clarifies allocating antennas on the front and rear side of the vehicle, which enables despreading Doppler frequency shift, gives better performance than allocating antennas on left and right sides. Further, cosine-gain-element adaptive array gives better performance here, too.

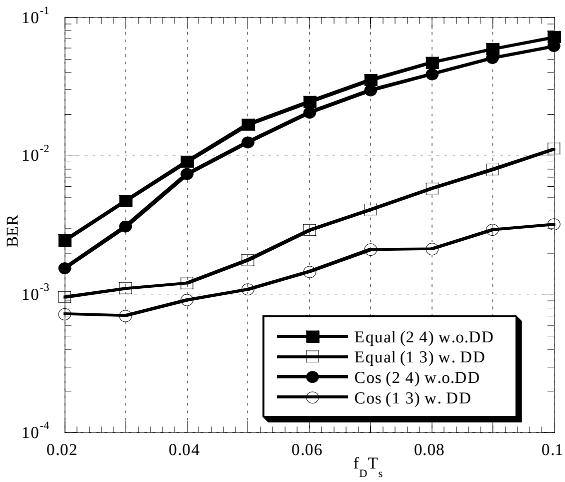


Fig.8 performance comparison between the use of element 2,4 and 1,3 (SNR=40dB)

5. Conclusions

This paper has evaluated the mobile receiving quality of Omni-directional- and directional-element OFDM adaptive array antenna consisting of four elements which are placed on the windows of a vehicle. Simulation results confirm that Doppler despreading applied cosine-gain-element adaptive array antenna gives the better BER characteristic. The paper also verifies that allocating cosine-gain elements on front and rear side of the vehicle gives better performance than installing them on right and left sides when receiving signals only with two element adaptive array antenna.

REFERENCES

[1] P.S. Wijesena, Y. Karasawa, "Beam-space adaptive array antenna for suppressing the Doppler spread in OFDM mobile reception," IEICE Trans. Commun., vol.E87-B, no.1, pp.20-28, Jan. 2004.

[2] T. Suzuki, S. Sampei and N. Morinaga, "Directive antenna diversity reception scheme for an adoptive modulation system in high mobility land mobile communications," IEICE Trans. Commun. Vol. E79-B, No.3, pp. 335-341, March 1996.

[3] M. Budsabathon, S. Hane, Y. Hara and S. Hara, "On a novel pre-FFT OFDM adaptive antenna array for signal suppression," IEICE Trans. Commun., vol.E86-B, no.6, pp.1936-1945, June. 2003.