A novel adaptive array for multi-carrier transmission

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1. Introduction

Deterioration of communication quality in land mobile communications is mainly caused by distortion of a received signal due to incidence of multi-path waves [1]. To compensate the distortion and to improve the communication quality, various techniques such as adaptive arrays [2] and adaptive equalizers [1] have been studied. In recent years, also a multi-carrier transmission technique has been attracting much attention as a promising scheme to realize a high-efficiency and high-quality communication [3]. In the case of the multi-carrier transmission, by decreasing a transmission rate per sub-carrier, effect of the multi-path wave can be relieved. To realize the high-speed mobile communication with the multi-carrier system, however, several problems have to be solved. Especially, development of techniques to decrease the effect of the multi-path waves with a long delay and Doppler effect due to movement of mobile terminals is indispensable [4].

In this paper, a novel algorithm for the adaptive array that is suitable for the multi-carrier transmission will be proposed. In the proposed system, a spectrum envelope of the received multi-carrier signal is detected and utilized to control a directional pattern of the array antenna. Furthermore, a configuration of the adaptive array to detect the spectrum envelope of the received multi-carrier signal will be provided.

2. Adaptive array for multi-carrier transmission

2.1 Configuration of proposed system

Concept of the proposed algorithm can be interpreted as the constant modulus algorithm (CMA[5]) which is applied to signals sampled in the frequency domain.

A configuration of the proposed adaptive array is shown in Fig.1. The signals received by the antenna elements are weighted by the complex multipliers and combined together. Then, the combined signal is inputted into the receiver of multi-carrier transmission. The combined signal is separated to the sub-carrier components and they are demodulated. The demodulated low-speed data are converted to the high-speed data by using the parallel serial converter as usual receiver of multi-carrier transmission. The signals separated to the sub-carrier components are also inputted to the controller to determine the weight coefficients.

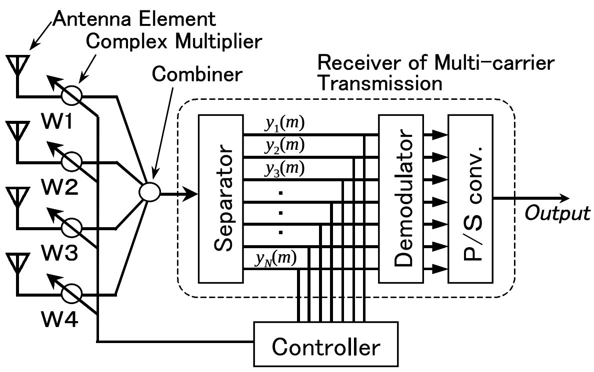

Fig.1 Configuration of Proposed Adaptive Array

2.2 Algorithm of proposed system

When the desired wave and the multi-path waves are received together, the spectrum of the received signal is distorted due to the multi-path waves even if all of the transmitted sub-carriers are the same in amplitude. However, the signal spectrum of the combined signal is almost flat when deep nulls on a directional pattern are formed in the directions of the multi-path waves and only the desired wave is received. Thus, the weight coefficients for each antenna element should be controlled so that the spectrum of the combined signal becomes flat.

In order to detect the signal spectrum, in general, an additional tool such as a spectrum analyzer is needed. Here, instead of the spectrum analyzer, the signals outputted from the separator in the receiver are utilized in the proposed system. This is because the amplitude of each separated signal indicates intensity of the corresponding sub-carrier that is closely related to the spectrum of the combined signal. By adopting the configuration shown in Fig.1, the distortion of the spectrum of the combined signal can be easily detected. Hence, the received multi-carrier signal, which is transmitted with the sub-carriers having the same amplitude, is separated and the weight coefficients are determined so that the separated signals become the same in the amplitude.

The control method of the weight coefficients is described as follows. Let $y_1(m)$ $y_2(m)$ $\cdots$ $y_N(m)$ represent the separated signals after m times of iteration and σ represents objective amplitude for each sub-carrier. Cost function $Q(m)$ of the proposed system is expressed as

$$Q(m) = \sum_{n=1}^{N} \left| \left| y_n(m) \right|^2 - \sigma^2 \right|^2 \tag{1}$$

Here, N indicates the number of sub-carriers. The cost function implies the distortion of frequency characteristics of the combined multi-carrier signal. When the cost function is minimized, all the amplitudes of sub-carriers become the same and then it is expected that nulls are formed in the directions of the multi-path waves on the directional pattern of the array antenna.

3. Computer Simulation

3.1 Condition of Simulation

The simulation is carried out on equivalent base-band systems. Conditions of the simulation are shown in Table 1. It is assumed that the desired wave and one undesired wave arrive at a receiving point. We consider following two types for the undesired wave.

1) Case 1; The undesired wave originates from the same transmitting antenna as that for the desired wave, but has the different path from the desired wave. It is, so called, the multi-path wave.
2) Case 2; The undesired wave is transmitted from the antenna which is different from that for the desired wave. Hereafter, we call this type wave “interference wave”.

An OFDM signal is generated using IFFT (Inverse Fast Fourier Transform) with 16 points in the simulation. The IFFT is operated symbol by symbol and the guard period is inserted in the front part of each symbol after the operating the IFFT.

We will compare performance of the proposed system with that of the conventional CMA adaptive array whose scheme is shown as follows:

- A single carrier signal modulated with differential QPSK is used.
- Weight coefficients are determined so as to minimize time variation of the amplitude of combined signal.

In this paper, DUR stands for the power ratio of the desired wave to the multi-path wave, SIR stands for the power ratio of the desired wave to the interference wave.

Table 1 Conditions of Simulation

Number of Sub-carriers	10 (OFDM)
Modulation	Differential QPSK
Length of Guard Period	1/8 Symbol Length
No. of Arrival Waves	2 Waves
Directions of Arrival	0 ° (Desired Wave) 60 ° (Undesired Wave)
DUR of Arrival Waves	3 dB
SNR of Desired Wave	20 dB
No. of Elements	4 Elements
Arrangement of Elements	Square Array
Distance of Elements	0.5 Wavelength
Algorithm	CMA
Optimizing Method	Marquardt Method [6]

3.2 Suppression performance for multi-path wave (Case 1)

Figure 2 shows the directional patterns of the array antenna. The thick arrows and the numbers in the figure indicate the directions of arrival and the numbers of iteration, respectively. It can be seen that a deep null is formed after several times of iteration and thus the multi-path wave is suppressed sufficiently.

Furthermore, it is investigated how the delay of the multi-path wave affects performance of the proposed system. Figure 3 shows the DUR value of the combined signal after iteration of 100 times when the delay(τ) of multi-path wave is varied. For comparison, the DUR value of the conventional CMA adaptive array is also shown by dashed line. The delay on the abscissa is normalized with a symbol length of the single carrier modulated with differential QPSK. The bit rates of all system in Fig.3 are the same. It can be seen following results from Fig.3.

1) The multi-path wave that has the long delay more than approximate 0.3 symbol length can be suppressed by the proposed system.
2) The suppression performance of the proposed system for the multi-path wave does not differ much from that of the conventional CMA adaptive array.

It is verified that the proposed system utilizing the spectrum of combined signal for the control of the directional pattern is an effective method to suppress the multi-path wave in the multi-carrier transmission system.

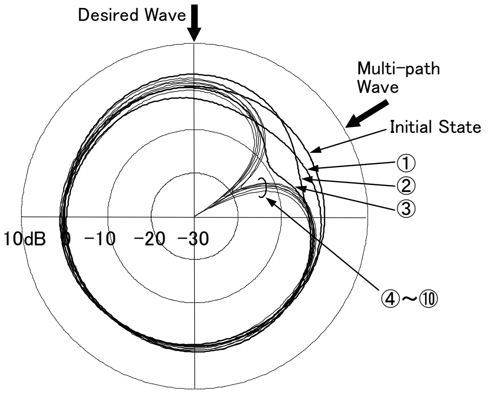

Fig.2 Directional pattern

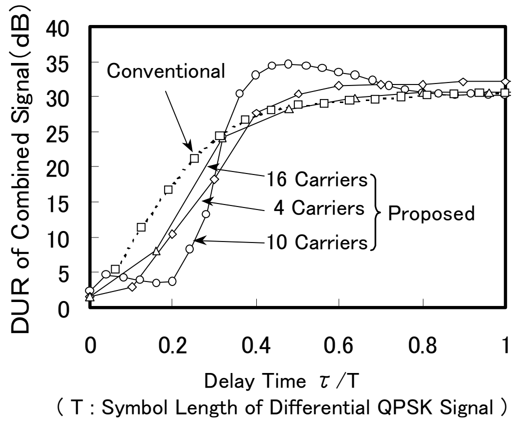

Fig.3 Suppression Performance for Multi-path Wave

3.3 Suppression performance for interference wave (Case 2)

In this section, the suppression performance for the interference wave will be shown. We assume at first that a continuous wave (CW) arrives as the interference wave besides the desired wave. The SINR (Signal to Interference plus Noise power Ratio) value of the combined signal after iteration of 100 times is shown in Fig.4 when the SIR (Signal to Interference power Ratio) of the arrival waves is varied. It is shown that the SINR value of the conventional CMA adaptive array decreases when the interference wave is stronger than the desired wave (SIR<0(dB)). It is because that the strongest wave in the arrival waves is captured in the case of the conventional CMA adaptive array as already clarified [7]. In contrast with the above, the SINR value of the proposed system does not decrease so much even if the interference wave is stronger than the desired wave. These results are explained as follows.

In the proposed system, the weight coefficients are controlled so that the separated signals become the same in the amplitude. Unfortunately, the desired wave is suppressed and only the interference wave is received, then the amplitude of all the separated signals must decrease except for a separated signal that correspond to the frequency of the interference wave. In this case, all of the separated signals cannot be the same in the amplitude.

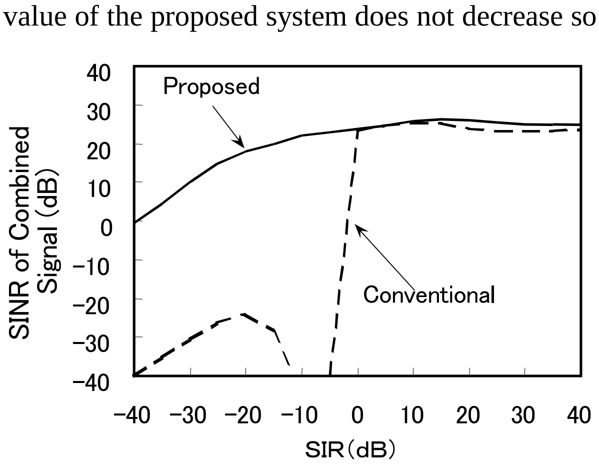

Fig.4 Suppression Performance for Narrow-Band Interference Wave

Furthermore, we investigated effect of a bandwidth of the interference wave. The SINR value of the combined signal is shown in Fig.5. The parameter is the bandwidth of the interference wave and the BW in the figure means the bandwidth of one sub-carrier of transmitted OFDM signal. It is found from Fig.5 that the value of the SINR tend to decrease as the bandwidth of the interference becomes broad. When the value of the SIR larger than –20dB, however, the SINR does not decrease so much and satisfactory value of SINR can be obtained.

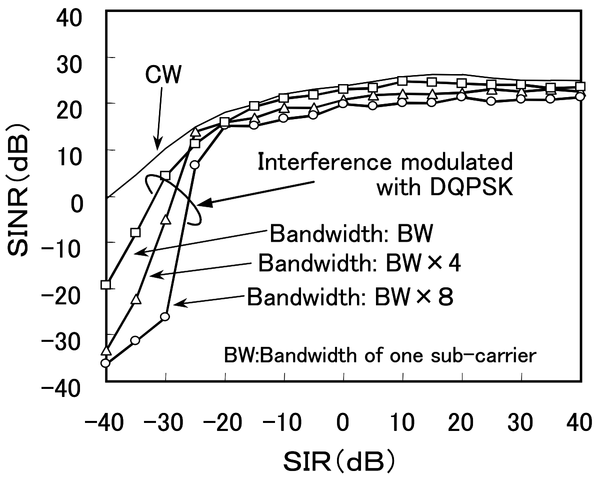

Fig.5 Effect of Bandwidth of Interference

4. Conclusion

A novel adaptive array that utilizes the frequency characteristics of multi-carrier signal has been proposed. Furthermore, the configuration of the adaptive array has been shown. By adopting the proposed configuration, the spectrum of the multi-carrier signal can be easily detected.

Next, in order to investigate the performance of the proposed adaptive array, computer simulation has been conducted. As a result, it is found that the desired wave is captured well even if the interference wave is stronger than the desired wave.

The conventional CMA adaptive array has a serious problem that the interference wave is captured when it is stronger than the desired wave. It can be said that reliability of the conventional CMA adaptive array is not enough because possibility of occurrence of the interference wave is not low. On the other hand, it is extremely rare that the proposed adaptive array captures the interference wave. Therefore, we can say that the proposed adaptive array is a robust system compared with the conventional system.

For the future study, we are planning to conduct the performance evaluation of the proposed adaptive array in more realistic environments by computer simulations and experiments.

[Acknowledgments]

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