Directional Pattern Control Method for SDMA Base Station Utilizing Ultrasonic Waves

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Abstract This paper proposes a directional pattern control method that utilizes the direction of arrival (DOA) of an ultrasonic wave to control the base station of a communication system and evaluates the accuracy of the DOA using the ultrasonic wave. The simulation results show that the DOA can be estimated correctly even in an environment where the difference in the propagation path length between the arrival multi-path waves is short.

1. INTRODUCTION

The techniques for estimating the direction of arrival (DOA) such as the MUltiple SIgnal Classification (MUSIC) algorithm have been investigated because information regarding the mobile terminal location is important in Space Division Multiple Access (SDMA) systems [1] [2] [3]. However, the accuracy of the DOA estimation degrades due to a high correlation between the arrival waves in the case of an environment with a short propagation distance such as for indoor wireless communications and Road-to-Vehicle Communications. In addition, the correlation between ultrasonic multi-path waves is very small because the propagation speed of the ultrasonic waves is much slower compared to that of radio waves [4]. A directional pattern control method that controls the directional pattern of a base station in a communication system using ultrasonic waves is proposed in this paper. Furthermore, the accuracy of the DOA estimation using the ultrasonic waves is evaluated by computer simulation.

2. DIRECTIONAL PATTERN CONTROL METHOD UTILIZING ULTRASONIC WAVES

The concept and the configuration of the proposed system are shown in Fig. 1. Each mobile terminal transmits both radio waves for communications and ultrasonic waves for estimating the DOA, which has a sharp autocorrelation. On the base station side, an array antenna for communications and a microphone array for estimating the DOA are used in the same arrangement. The ultrasonic wave received at each microphone is input to the matched filter (MF) and the output waveform from the MF represents the delay profile at the microphone. Thus, the DOA of the ultrasonic waves can be estimated from the difference in the time of arrival (TOA) at the microphone. If the propagation path of the radio wave is the same as that of the ultrasonic wave, the DOA of the ultrasonic wave represents that of the radio wave. Since the propagation speed of the ultrasonic wave is

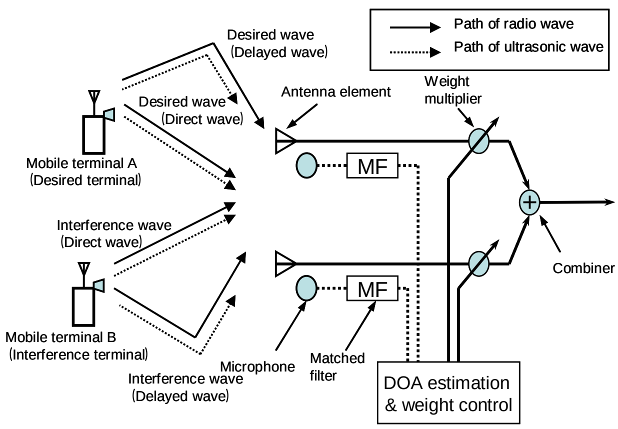

Fig. 1 Proposed SDMA base station using ultrasonic wave

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very slow compared with that of the radio wave, it is expected that the estimation accuracy is not deteriorated even when the difference in the path length of the multi-path waves is very short.

The weight coefficients for the array antenna are decided based on the DOA estimated using the ultrasonic waves. Many kinds of beamforming algorithms such as the Winner solution and the Directional Constrained Minimization of Power (DCMP) can be applied if the DOA is known [5].

3. ACCURACY OF DOA ESTIMATION EMPLOYING ULTRASONIC WAVES

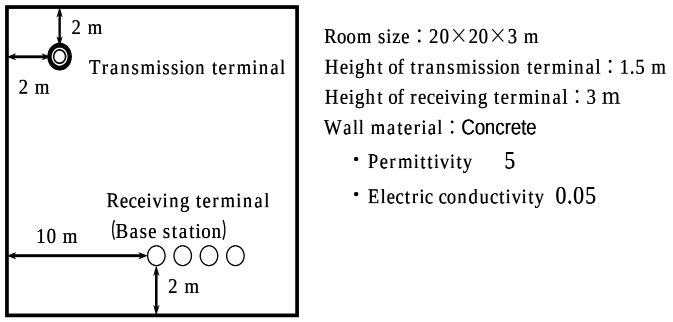

Fig. 2 Indoor environment

In the proposed method, the accuracy of the DOA estimation using the ultrasonic waves in an indoor environment is very important to forming the appropriate directional pattern. Thus, we evaluated the accuracy of the DOA estimation using the indoor propagation model shown in Fig. 2. It is assumed that the walls of the room are made of concrete, and the array of the antenna and that of the microphone are composed of four elements that have a 6-cm spacing. It is also assumed that all microphones and antenna elements have an omni-directional pattern. The propagation of the radio waves and the ultrasonic waves is analyzed using the Ray-launching method. The center frequency of the radio wave is 2.5 GHz and bandwidth is 20 MHz. The center frequency of the ultrasonic wave is 40 kHz and the bandwidth is 40 kHz.

The following three methods are applied to the signal that is received at each reception element.

a) A MF is applied to the ultrasonic wave (proposed method).

b) MUSIC is applied to the ultrasonic wave.

c) MUSIC is applied to the radio wave received by the antenna elements.

For Method **a)**, only two elements are used. A transversal filter comprising 32 taps is used for the MF. Moreover, the Signal to Noise power Ratio (SNR) is set to 20 dB for the first arrival wave.

First, the estimated results are shown in Fig. 3 when two waves arrive (only one direct wave and one first delayed wave). Methods **a)** and **b),** which utilize the ultrasonic wave, can closely estimate the accurate direction of arrival (arrows in figure). However, the estimation accuracy degrades in Method **c)** because the delay time of the radio wave is short and the correlation between the arrival waves becomes large.

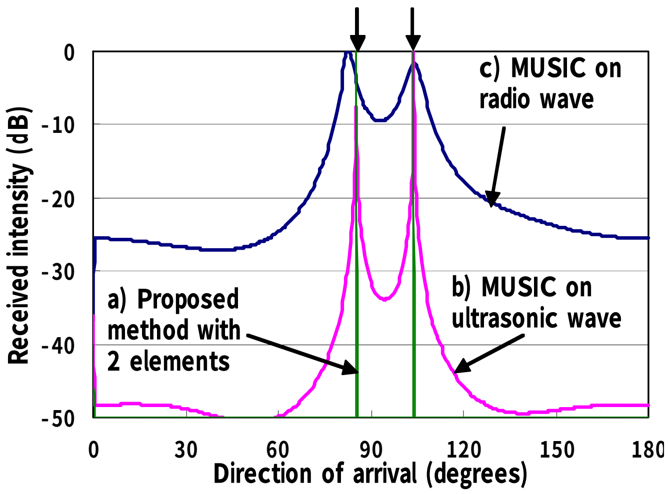

Fig. 3 DOA estimation results (Arrival of 2 waves)

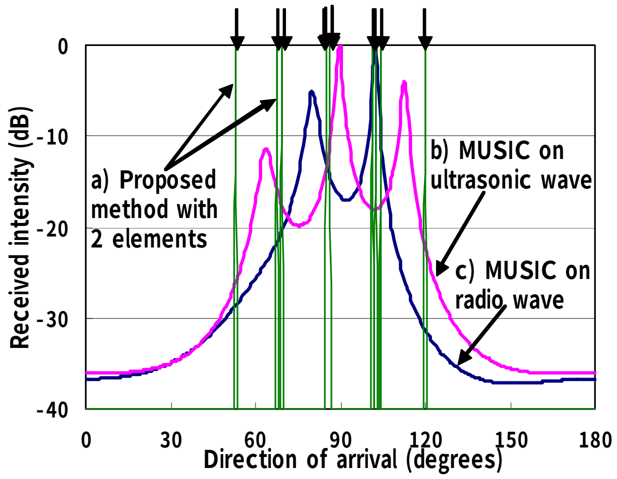

Fig. 4 DOA estimation results (Arrival of 11 waves)

Next, the estimated results when there are 11 waves are shown in Fig. 4. Here, the arrival waves that have the amplitude of greater than –10 dB compared to the direct wave are taken in account. The DOA of all of 11 waves can be correctly estimated by using two elements in the proposed method. However, the MUSIC method cannot provide a correct estimate in either case of the radio wave or ultrasonic wave because of shortage of the number of freedom of the array. Based on these results, it can be said that the DOA can be estimated correctly using the proposed method even when the number of arrival waves exceed the number of freedom of the array.

4. EFFECT OF SNR ON ACCURACY OF DOA ESTIMATION

The estimation accuracy of each of the following methods is compared.

A) Proposed with two elements: the proposed method is applied to the signal received by only two microphones elements (the first element and the second element).

B) Proposed with four elements: the proposed method is applied to three pairs of microphones (the first and second microphones, the second and third microphones, the third and fourth microphones), and the estimated results are averaged.

C) Using the ultrasonic wave without a MF: the MF is not used in the configuration depicted in Fig. 1, and the DOA is estimated from the time difference of the peak of the received signal.

D) MUSIC on the ultrasonic wave: the MUSIC method is applied to the ultrasonic wave received by four microphones.

E) MUSIC on the radio wave: the MUSIC method is applied to the radio wave received by four antenna elements.

Figure 5 shows the estimated error of the above five methods for various SNRs. The vertical axis indicates the average estimation error of 1000 trials. Since the propagation speed of the ultrasonic wave is very slow compared to the radio wave even if the propagation path is the same, the correlation of the ultrasonic wave is much lower than that of the radio wave. Thus, the estimation error of **D)** (MUSIC on the ultrasonic wave) is smaller than that of **E)** (MUSIC on the radio wave).

The accuracy of Methods **A)** and **D)** is almost the same when the SNR exceeds 15 dB. However, the estimated error of Method **D)** is smaller than that of Method **A)** when the SNR is lower than 15 dB. The improved version of the proposed method, Method **B),** has the same accuracy as Method **D)**. Since the computational load of Method **B)** is much less than that of Method **D)**, it can be said that the proposed method is effective as a directional pattern control method. If the MF is not used as in Method **E)**, sufficient accuracy cannot be obtained.

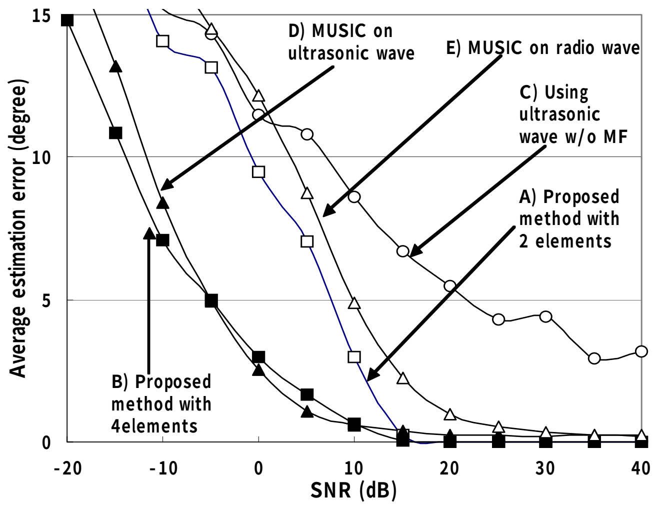

Fig. 5 Average estimation error for SNR

5. CONCLUSION

A base station control method for the SDMA system using the ultrasonic wave was proposed, and the estimation accuracy of the method was investigated. It was shown that the proposed method provides an accurate estimate even in a propagation environment with a short path difference between arriving waves. Moreover, it was shown that the estimation accuracy of the proposed method was almost the same as the MUSIC method using the ultrasonic wave. The operational load of the proposed method is much less than that of the MUSIC method, and the proposed method can be used in an environment where the number of arrival waves exceed the number of freedom of the array. Therefore, it can be said that the proposed method is an effective base station control method for short-range communication systems.

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