Effects on AGC for DOA Estimation under Multipath Environments

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1 Introduction

It is necessary to investigate the exact propagation characteristics under the multipath environment, in particular, DOA (Direction Of Arrival) of radio wave is important information, and various DOA algorithms have been proposed. The multi-channel receiver for DOA estimation is required to have correct amplitude and phase information. The normal receiver includes AGC (Automatic Gain Control) circuit which is well utilized not to saturate received power level fluctuated by multi-path fading. The information of AGC level of each receiver channel should be included for correct DOA estimation. On the other hand, reducing ADC (Analog to Digital Converter) resolution enable more high-speed DOA estimation by low cost system. It is necessary to clarify the relation between the dynamic range of AGC and resolution of ADC. When the system dynamic range of the received signal is limited by the limiter, its effect on DOA estimation accuracy has been examined recently [1]. In ref. [1], the limiter is applied to each element, and the estimation error in average is about 5° by using 8-bit ADC for 8-element antenna array receiving 4 incident waves. This paper presents the relation between the accuracy of DOA estimation and dynamic range of common AGC for high-speed and higher accuracy system.

2 Common AGC Receiver System

Two AGC models are investigated to apply AGC to received signal of antenna array. One is a method of applying AGC to each element of antenna array. In this method, the gain of received signal of each element is different each other. Another is a use of common AGC to all the elements, where each element has the same gain. In this paper, we use MUSIC algorithm based on eigenvalue decomposition of the correlation matrix. The correlation matrix derived from the array received signal is expressed by eq. 1, and its matrix after applying AGC is calculated from eq. 2. In the following equations, the gain of each element is g_i, R_{xxAGC} is a product of R_{xx}, and $g_i g_j (i,j = 1, 2, ..., m)$ is the mutual product of $g_1 \sim g_m$. In eq. 2, the correlation matrix using AGC is different from that of no AGC, then the eigenvalue and the eigenvector are changed.

$$R_{xx} = E[XX^H] = ASA^H + \sigma^2 I \tag{1}$$

$$\begin{aligned} R_{xxAGC} &= E[(GX)(GX)^H] \\ &= E[GXX^H G^H] \\ &= GR_{xx}G^H \end{aligned} \tag{2}$$

$$G = \begin{bmatrix} g_1 & 0 & \dots & 0 \\ 0 & g_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & g_m \end{bmatrix} \tag{3}$$

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The estimation error shown in ref. [1] is caused by difference in the correlation matrix of the signal limited in amplitude with the case of no limiter. If the incident wave with the amplitude more than 10-bit is received in that receiver, the estimation error increases. In the common AGC presented in this paper, R_{xxAGC} is given by $GR_{xx}G^H$, then the correlation matrix of the signal after AGC is similar to the original matrix before AGC. The estimation errors depend on the resolution of ADC. This paper shows the minimum ADC resolution using a model of incident wave with angular spread.

3 Simulation Results

We investigate the degradation of estimation accuracy by limited amplitude of received signal by computer simulations. Fig. 1 shows the model of multipath fading, and the complex incident signal vector $s_c(t)$ is expressed as,

$$s_c(t) = \begin{bmatrix} \sqrt{P_1}\exp j2\pi[f_c + f_d \sin\theta_1]t + \alpha_1 \\ \sqrt{P_2}\exp j2\pi[f_c + f_d \sin\theta_2]t + \alpha_2 \\ \vdots \\ \sqrt{P_L}\exp j2\pi[f_c + f_d \sin\theta_L]t + \alpha_L \end{bmatrix} \tag{4}$$

where, L is the number of incident wave, $P_L(l = 1, 2, \ldots M)$ is the power of incident wave, f_c is carrier frequency and f_d is maximum Doppler frequency, respectively. The amplitude fluctuation of the received signal of antenna array is modeled as a Rayleigh distribution, while the initial phase of the multipath component is uniformly distributed [2]. The speed of the mobile terminal is assumed to be constant during a snapshot period. The angular spread of the incident wave is also introduced into this model as shown in Fig. 2 [3]. The scattered point is randomly set on the circumference of circle, and its radius is decided with angular spread and distance from the array. The power distribution of scattered wave in one cluster is Gaussian distribution expressed as eq. 6, where θ_0 is the central angle of the cluster and σ is its standard deviation. Fig. 2 shows that the l-th cluster of central angle θ_l is received by M-element antenna array. The number of the scattered wave in each cluster is N_{SC}. When the angle of the i-th scattered wave in the l-th cluster is θ_{il}, the signal entering from the direction of θ_{il} is expressed as follows.

$$s_c(t) = \sqrt{P_{il}}\exp j2\pi[f_c + f_d sin\theta_{il}]t + \alpha_{il} \tag{5}$$

$$P(\theta) = \frac{1}{\sqrt{2\pi\sigma}}\exp -\frac{(\theta-\theta_0)^2}{2\sigma^2} \tag{6}$$

One cluster is composed from signals of N_{SC} as shown in eq. 5, and the scattered wave in one cluster is perfectly correlated each other ($\alpha_{1l} = \alpha_{2l} = \ldots = \alpha_{N_{SC}l}$).

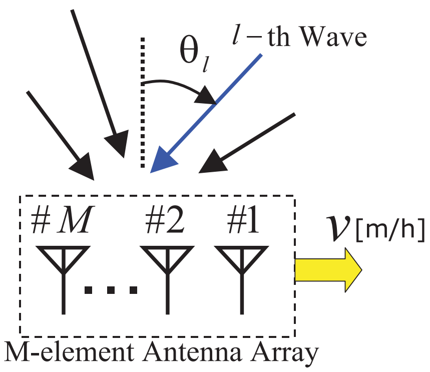

Figure 1: Multipath model

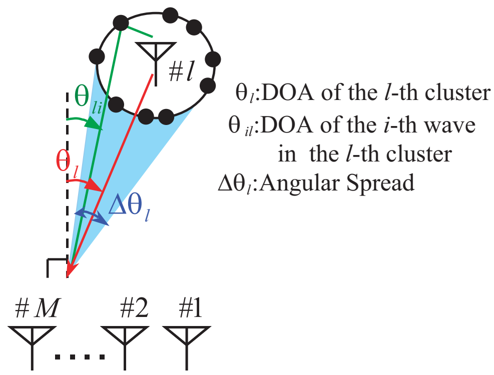

Figure 2: Angular spread model

The number of each cluster is 30, and σ is 3°. In this paper, DOA is estimated by clusters. Four clusters is received at antenna array from the direction of $\theta_0 = -28, -10, 15, 30°$, or three clusters is received from the direction of $\theta_0 = -28, -10, 15°$. The received signal is sampled by ADC after applying AGC. The SNR of each cluster is 20 dB. The dynamic range D of AGC corresponds to the number of bit N of ADC as,

$$D = 20 \log_{10}(2^N - 1)[\text{dB}] \tag{7}$$

MUSIC algorithm requires the number of wave, then we assume that it is already given in advance. In broadband mobile communications, the signal is not received continuously from the same mobile station, and the AGC is operated in a burst. In this paper, the gain is constant in the burst. Table 1 shows the simulation parameters.

Table 1: Simulation Parameters

Incident wave	Sinusoidal
Carrier frequency	2[GHz]
Maximum Doppler frequency	About 74[Hz]
Array shapes	8-element linear array
Spatial Smoothing Scheme (Sub-array)	Forward/Backward (5)
Element space	$\lambda/2$
Snapshot	100 [sample]
Trial	100

The examples of estimation result are shown in Figs. 3 and 5, and x-axis is trial number and y-axis is DOA angle. The MUSIC spectrums for the examples are shown in Figs. 4 and 6. These figures show the spectrums of 5 trials repeatedly. Figs. 7 and 8 show the estimation RMSEs (Root Mean Square Error) for 3 and 4 incident waves. When the dynamic range is more than 8 bits, the RMSEs of 3 waves and 4 waves are small enough such as 0.98° and 1.30°. This error is not caused by limiting amplitude and caused by angular spread of incident wave. When the dynamic range is 6 bits, the error for 3 incident waves is 1.32°, and the error for 4 waves is 2.79°. Moreover the accuracy is deteriorated greatly with 7.56° and 8.50° in case of 3 waves and 4 waves for less than 4 bits.

According to the results, dynamic range of AGC and ADC require more than 8-bit, and the estimation RMSE of 4 waves is very small with 1.30°. This error 1.30° is smaller than the average error 5° of applying limiter to each antenna element [1], and the common AGC is very useful under the multipath environment.

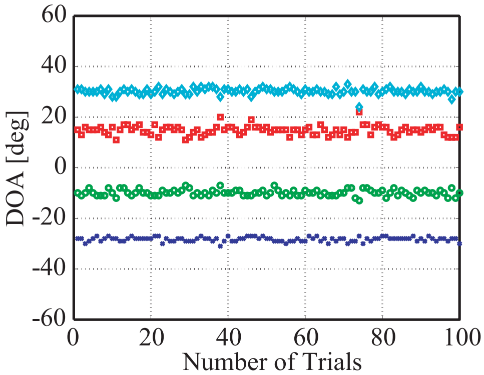

Figure 3: The estimation result of 8 bits

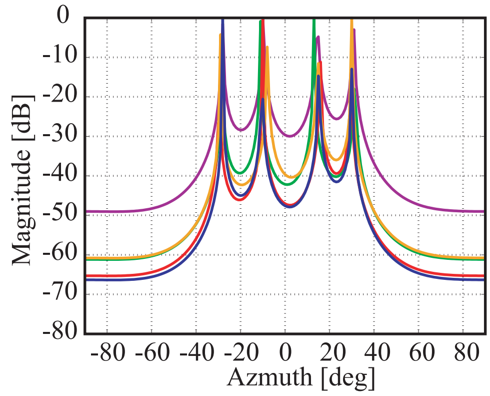

Figure 4: MUSIC spectrums in 8 bits

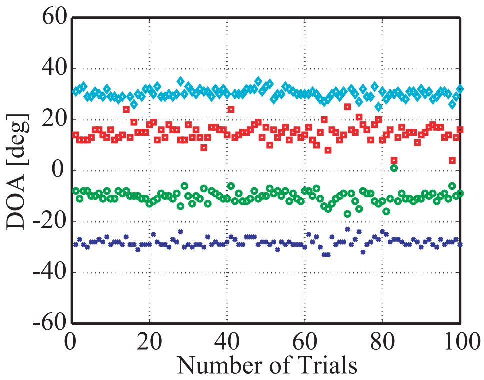

Figure 5: The estimation result of 6 bits

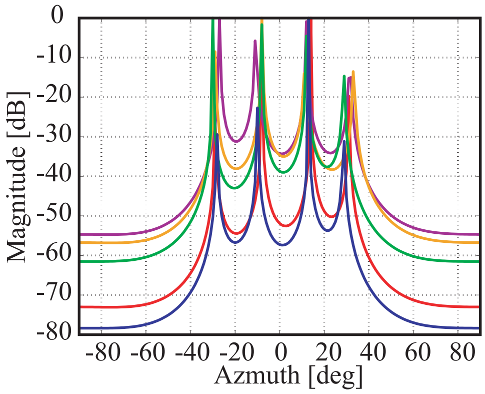

Figure 6: MUSIC spectrums in 6 bits

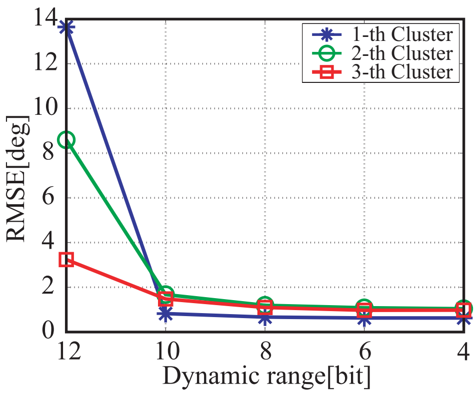

Figure 7: The estimation error of 3 waves

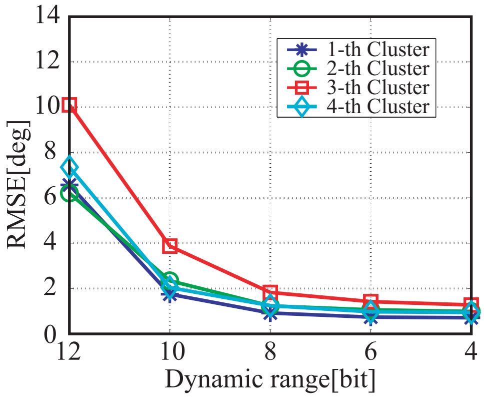

Figure 8: The estimation error of 4 waves

4 Conclusion

This paper presented the relation between accuracy of DOA estimation and dynamic range of AGC and ADC under the multipath environment for high-speed and higher accuracy DOA estimation. The estimation accuracy by limiting amplitude of received signal was examined with the angular spread model by computer simulations. The result showed that the common AGC is very useful and the resolution of ADC in the receiver is required more than 8-bit.

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