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A Study on Power Assignment of Hierarchical Modulation Schemes for Digital Broadcasting

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SUMMARY In the future satellite broadcasting system in 21 GHz band, the rainfall attenuation is a most significant problem. To solve this problem, the hierarchical transmission systems have been studied. This paper analyzes the performance of the hierarchical modulation scheme from the view point of power assignment in the presence of the rainfall attenuation. This paper shows an optimum power assignment ratio to maximize the spectral efficiency and the signal-to-noise ratio of received image, and these optimum ratio is varied with the measure of system performance.

key words: *digital broadcasting, HDTV, hierarchical modulation, graceful degradation*

1. Introduction

Recently, Digital satellite broadcasting services in 21 GHz frequency band have been studied for digital HDTV (High Definition Television) broadcasting [1]. Satellite broadcasting systems using the frequency band of 21 GHz are capable of broadcasting broadband information and using smaller aperture antenna, compared with the conventional satellite broadcasting system in 12 GHz band. Despite these advantages, the transmission performance is significantly degraded due to rainfall attenuation.

One solution of this problem is to give enough power margin by increasing the transmission power or using large aperture antenna. But in broadcasting satellite, power resources are limited so severely that it is difficult to increase the transmission power. Furthermore, to use larger antenna costs too much.

Hierarchical transmission has been investigated to solve this problem without increase total transmission power [2],[3]. The hierarchical transmission makes the degradation of received message's quality gradually, (*Graceful Degradation*). The idea of hierarchical transmission is to transmit information with higher reliability according to it's importance. For example, when we transform pictures to frequency domain, low frequency components are more important than high frequency's because the low frequency components decide rough impression of picture and high frequency components refine it's details. The hierarchical transmission, improve the performance by transmitting low frequency components with higher reliability. When the channel quality degraded by rainfall, the hierarchical broadcasting systems can avoid the outage at the sacrifice of the degradation of received quality.

The hierarchical transmission system consists of hierarchical source coding and hierarchical channel coding. The hierarchical source coding splits the source into two or more multilevel according to its importance. The digital video compression systems for HDTV, e.g. MPEG2 and so on, generally have hierarchical characteristic. And, the hierarchical channel coding is to assign the bandwidth and transmission power to each hierarchical signal in proportion to its quantity and importance.

Although in conventional studies of hierarchical transmission, the relation between power assignment and broadcast ranges are clarified [1] and performance of hierarchical transmission system under arbitrary power assignment are analyzed [3],[4]. But the optimization of power assignment have not been investigated. By assigning higher power to the important information levels, we can improve the outage probability performance. However, since we can assign few powers to the refinement levels when we assign higher power to the important levels and average image quality become worse. Conversely, by assigning much power to the refinement information levels, the outage probability performance becomes worse. Therefore, there is an optimum power assignment ratio to maximize the average message's quality.

In this paper, we clarify the optimization of the power assignment ratio. We suppose that the systems use quadrature amplitude modulation (QAM) for improving spectral efficiency. To get optimum power assignment, we analyze the relation between power assignment ratio and the average received message's quality for two hierarchical modulation systems with two performance measures.

2. Hierarchical Modulation System

A communication system consists of source coding, which removes redundancy from a source, and channel coding, which inserts redundancy to combat a noisy channel. Some source coders can split the source into

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two or more levels according to its importance. We call this kind of the source coders "hierarchical" coders in the followings. The quality of receiving message depends on which level of information is lost. Thus, the average quality of the system can be improved by changing the channel coding rate or the transmission power according to the level of importance. In this section, we show the hierarchical modulation systems, in which the higher importance level of information, the more transmission power is assigned.

Figure 1 shows the block diagram of two-level hierarchical source coder. In this system, the source is split into base information and refinement information. Suppose that the base and refinement information bit rates are r_1 and r_2, respectively, and the refinement information cannot available without base information. The base and refinement information are fed into hierarchical modulator. In this paper, we consider two types of the hierarchical modulation schemes. One is so called "embedding" modulation, and another is "multicarrier" modulation.

In Fig. 2 we show the block diagram of the channel coding system based on the embedding modulation scheme. In the modulator, the base and refinement information are fed into M_1-QAM and M_2-QAM modulators, respectively [5]. Then, the modulated refinement information signal is superposed on the base signal. Figure 3 shows the constellation of the embedding 16-QAM signal where $M_1 = M_2 = 4$. In this figure, the base information bits select one of the 4 clusters, and the refinement information bits select one of the 4 constellation points within selected cluster. Suppose D_1 and D_2 be the minimum distance between clusters and the minimum distance within the cluster, respectively. Now, we define the power assignment ratio, R, in embedding 16-QAM system as

$$R = \frac{P_{base}}{P_{all}} = \frac{(D_1 + D_2)^2}{(D_1 + D_2)^2 + D_2^2}, \quad (1)$$

where, P_{base} is the average of assigned power for base-hierarchy transmission, and P_{all} is the average of total transmission power of the system.

Figure 4 shows the spectral efficiency performance of the embedding 16-QAM against the received C/N (carrier-to-noise power ratio). In this figure the embedding 16-QAM requires higher received C/N to achieve a spectral efficiency of 4 [bit/s/Hz] than conventional 16-QAM. But conventional 16-QAM requires higher received C/N to avoid outage than embedding 16-QAM. Therefore, this system can improves the total outage probability performance due to rainfall attenuation.

In Fig. 5, We show another type of the hierarchical modulation system named the multicarrier modulation system. In the multicarrier modulation system, the base and refinement information are transmitted through two separate channels, that is, each hierarchical information are transmitted with two different frequencies. In each channel, signal is modulated to 16-QAM. We achieve the hierarchical modulation by assigning the higher power to the base information channel.

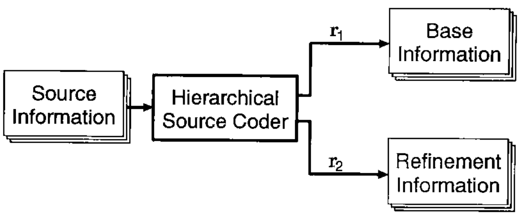


Fig. 1 Two-level hierarchical source coding system.

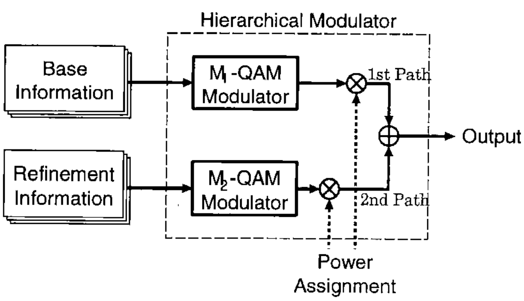


Fig. 2 Hierarchical channel coding system by embedding modulator.

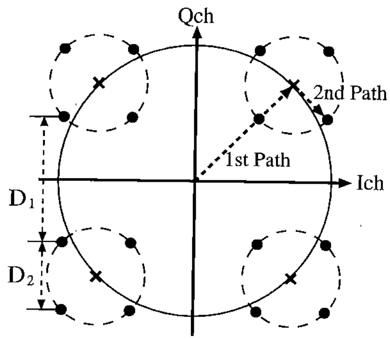


Fig. 3 An example of the embedding 16-QAM signal constellation.

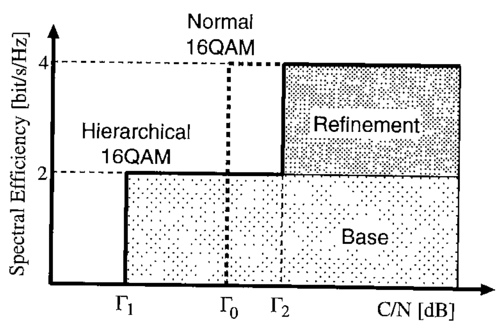


Fig. 4 An example of the stectral efficiency performance.

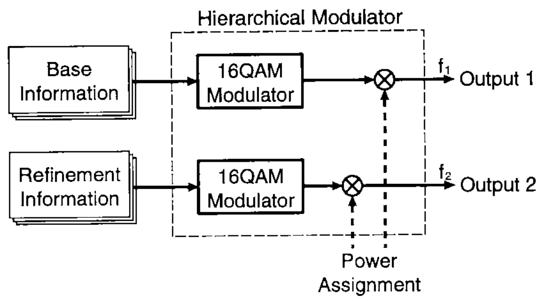


Fig. 5 Hierarchical channel coding system by multicarrier modulator.

3. Performance Analysis

The received signal is impaired by rainfall attenuation and multipath fading. In particular, rainfall attenuation will be a most significant problem in a future satellite broadcasting at 21 GHz. In this paper, we assume that only rainfall attenuation degrade the received signal, and amplifier of satellite transmitter has ideal characteristic.

In this section, we analyze the performances of two-level hierarchical 16-QAM systems in the presence of the rainfall attenuation. In a satellite channel, the rainfall attenuation can be approximated to a log-normal distribution [6]. Then, the probability that the attenuation (α [dB]) exceeds the threshold level (A [dB]) is given by

$$\begin{aligned} Prob(\alpha \geq A) &= 1 - F_{rain}(A) \\ &= \frac{1}{2}\mathrm{erfc}\left(\frac{\log_{10} A - m_e}{s_e\sqrt{2}}\right), \end{aligned} \quad (2)$$

where m_e is the mean, and the s_e is the standard deviation. This parameters depend on the locations of the satellite and the earth-station.

Now, we assume that Γ is the maximum C/N of channel (i.e. the C/N when it doesn't rain). And we suppose that the transmission of the base and refinement information require the BERs of P_{b1} and P_{b2}, respectively. Let $\Gamma_1(R)$ and $\Gamma_2(R)$ be the required C/N to receive the base and refinement information, that is, $\Gamma_1(R)$ is the required C/N to satisfy the BER of P_{b1} in the transmission of the base information and $\Gamma_2(R)$ is the required C/N to satisfy the BER of P_{b2} in the transmission of the refinement information. In embedding 16 QAM system, required C/N of base and refinement levels are given by

$$\begin{aligned} \Gamma_1(R) &= \frac{2}{1 - 2\sqrt{R(1-R)}}\left\{\mathrm{erfc}^{-1}(4 \times P_{b1})\right\}^2, \\ \Gamma_2(R) &= \frac{2}{1-R}\left\{\mathrm{erfc}^{-1}(2 \times P_{b2})\right\}^2. \end{aligned} \quad (3)$$

Similarly, in multicarrier system which use two 16-QAM signals, the required C/N of each level can be expressed as

$$\begin{aligned} \Gamma_1(R) &= \frac{\left\{10 \times \mathrm{erfc}^{-1}(8P_{b1}/3)\right\}^2}{R}, \\ \Gamma_2(R) &= \frac{\left\{10 \times \mathrm{erfc}^{-1}(8P_{b2}/3)\right\}^2}{1-R}. \end{aligned} \quad (4)$$

Then, the threshold level of the rainfall attenuation, $A_1(R,\Gamma)$ and $A_2(R,\Gamma)$, for the base and refinement hierarchy, which are also the function of R, are given by

$$\begin{aligned} A_1(R,\Gamma) &= 10\log_{10}\{\Gamma - \Gamma_1(R)\}, \\ A_2(R,\Gamma) &= 10\log_{10}\{\Gamma - \Gamma_2(R)\}. \end{aligned} \quad (5)$$

By using (5), we can analyze the relation between R and the average received signal qualities, such as the channel's outage probability, spectral efficiency, and received S/N (signal-to-noise ratio).

Suppose that the hierarchical modulation scheme satisfies the following condition, $\Gamma_1(R) \leqq \Gamma_2(R)$. Under the condition, the outage probability $P(R,\Gamma)$ is given by

$$\begin{aligned} P(R,\Gamma) &= 1 - F_{rain}(10\log_{10}\{\Gamma - \Gamma_1(R)\}) \\ &= 1 - F_{rain}(A_1(R,\Gamma)) \\ &= 1 - \frac{1}{2}\mathrm{erfc}\left(\frac{\log_{10}(A_1(R,\Gamma)) - m_e}{s_e\sqrt{2}}\right). \end{aligned} \quad (6)$$

Furthermore, by $A_1(R)$ and $A_2(R)$, we can get the average spectral efficiency as following. Suppose that q_1 is the spectral efficiency when only the base information is successfully received and that q_2 is the spectral efficiency when both the base and refinement information are perfectly successfully received. As we illustrated in Fig. 4, the spectral efficiency of q_1 is achieved when the instantaneous C/N is within the range between $\Gamma_1(R)$ and $\Gamma_2(R)$, and the spectral efficiency of q_2 is achieved when the instantaneous C/N exceeds $\Gamma_2(R)$. Then the average spectral efficiency is given by

$$Q(\Gamma) = q_1 F_{rain}(A_1(R,\Gamma)) + q_2 F_{rain}(A_2(R,\Gamma)). \quad (7)$$

In the two-level hierarchical 16 QAM system considered in this section, q_1 is two, (equivalent to the QPSK) and q_1+q_2 is four (equivalent to the 16 QAM). Add to these, in this paper, we evaluate the average S/N of the received images by replacing q_1 in (7) with the S/N of base images and q_2 in (7) with the S/N of the refined images.

4. Optimization of Power Assignment Ratio

If the statistical characteristic of the received signal strength is known, we can optimize the power assignment ratio. In this section, we analyze the relation between ratio of power assignment and the performance of hierarchical modulation system, in satellite channel impaired due to rainfall. This attenuation is, as mentioned

Table 1 Parameters of rainfall attenuation.

Parameters	Values
Frequency Band	21.2 GHz
Received Point	Tokyo
Satellite Position	130° E
m_e	−0.0624
s_e	0.516

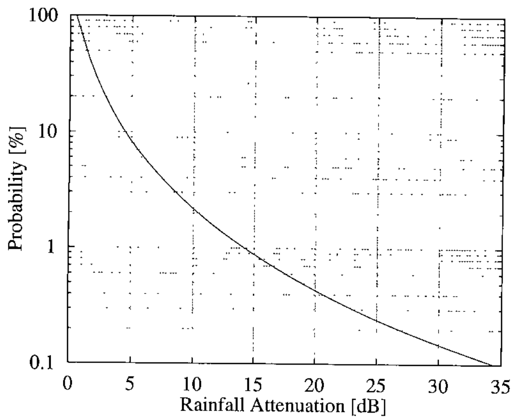
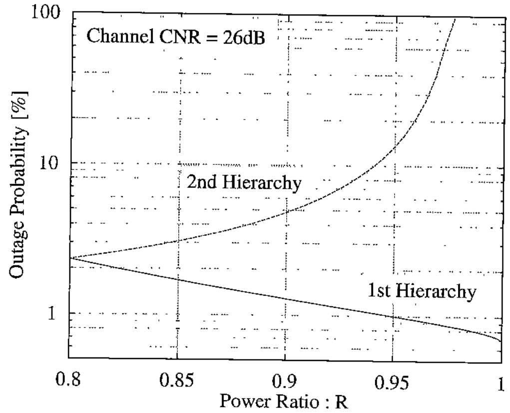


Fig. 6 The conditional probability of the rainfall attenuation.

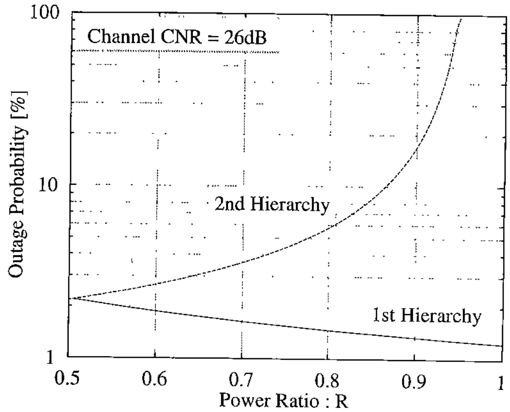
above, approximated to a log-normal distribution, because we assume that only rainfall attenuation impairs the received signal, and rainfall attenuation is approximated to a log-normally distribution. We assume that the parameters of rainfall attenuation shown in Table 1 is used in the following discussion. The distribution given by these parameters is the statistical one under the rainy condition which is about rainy 10% time out of a whole year. This conditional probability of the rainfall attenuation is shown in Fig. 6.

Figure 7 shows the outage probability of each hierarchy, where the threshold of required BER for each hierarchies $P_{b1} = P_{b2} = 10^{-3}$ and $\Gamma = 26$ dB. In this Figure, the higher power assignment ratio improve outage probability of base hierarchy, but it also cause the higher outage probability of refinement hierarchy. Although we have assumed that the system outage probability is dependent on the base hierarchy's one, the lack of refinement hierarchy information cause the deterioration of broadcasting service quality. Therefore, the system improve it's outage probability at the sacrifice of received image quality. In particular, the outage probability of refinement hierarchy is deteriorated immediately at R > 0.9. Figure 8 shows the relation between power assignment ratio and mean spectral efficiency, in embedding modulation system and multicarrier modulation system respectively.

In embedding modulation system, the relation between power assignment ratio and mean spectral efficiency are shown in Fig. 8 (a). From this figure, it is clear that system optimum power assignment ratio is $R = 0.82$, which maximize mean spectral efficiency. But,



(a) embedding modulation system.

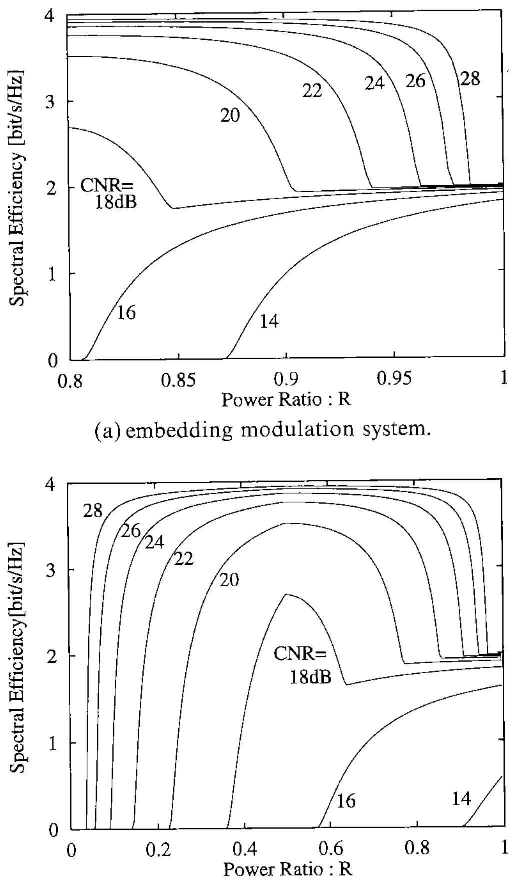


(b) multicarrier modulation system.

Fig. 7 Outage probability of each hierarchy vs. power assignment ration, R.

at the range of $\Gamma < 18$ dB, the information of refinement hierarchy cannot be received, so the mean spectral efficiency cannot exceed 2 bit/s/Hz, and optimum power assignment ratio is $R = 1.0$. And this figure also shows that when the channel has sufficient quality, mean spectral efficiency become constant at the range of $R < 0.9$. Figure 8 (b) shows the same relation in multicarrier modulation system. This figure shows that, the optimum power assignment ratio, which maximize mean spectral efficiency, is $R = 0.5$. The result explains that, when we optimize the system by mean spectral efficiency, to transmit each hierarchies with same power is the most effective setting. But the analyze of mean spectral efficiency does not correspond to judged quality by viewers, i.e. viewers can bear the degradation of resolution but they cannot bear outage.

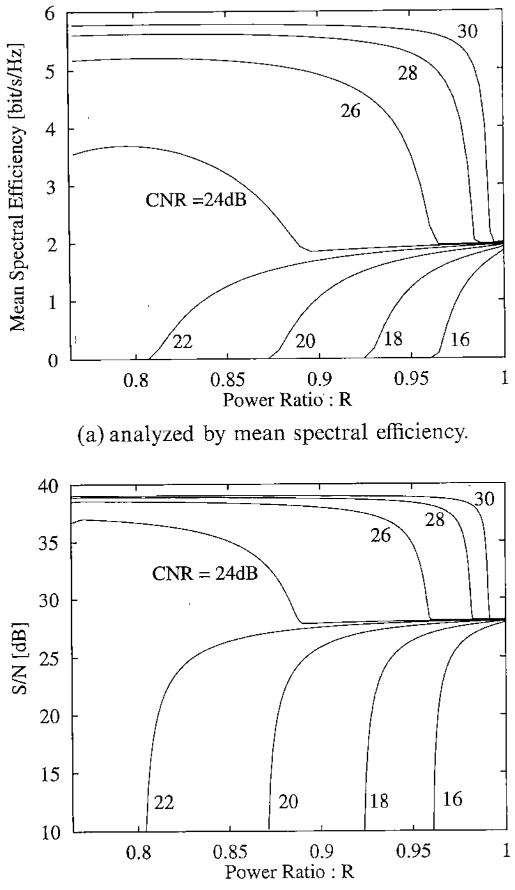
Then we analyze the effect of optimum power assignment ratio by the another measure of system performance. Here, we use the mean S/N of received image as another measure. The S/N of received image, by base information and by base-and-refinement information, are clarified in Ref. [2], when image information is split into hierarchy and transmitted by the em-



(a) embedding modulation system.

(b) multicarrier modulation system.

Fig. 8 Mean spectral efficiency vs. power assignment ratio, R.



(a) analyzed by mean spectral efficiency.

(b) analyzed by average signal S/N.

Fig. 9 Average performances in embedding 64-QAM system vs. power assignment ratio, R.

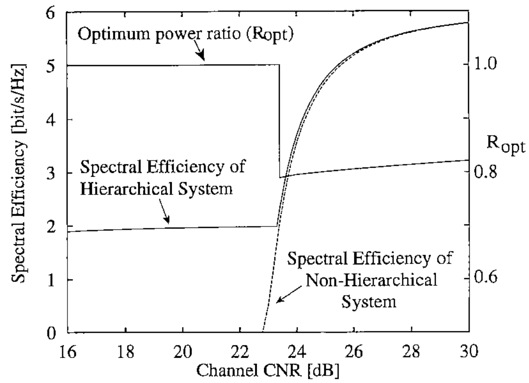


Fig. 10 Mean spectral efficiency under optimum power assignment ratio.

bedding 64 QAM and received. These are 28.2 dB and 39.2 dB respectively. By using these value and embedding 64 QAM, Fig. 9 shows the relation between system performance and power assignment ratio under two measures for performance.

These results are shown that the optimum power ratio for mean S/N analysis is less than that for mean spectral efficiency analysis, because the rise of performance by getting refinement information is larger than that of mean spectral efficiency analysis. In other words, the optimum power assignment ratio varies with the measure of system performance. So there is a needs of optimization by subjective evaluation, e.g. EBU method [7] and so on, because it gives the total broadcasting quality for a viewer.

Figure 10 shows the optimum power assignment ratio, R_{opt}, which maximizes the mean spectral efficiency, and the maximum mean spectral efficiency against the average C/N. This figure shows that, at the range of $C/N < 23.4$ dB, the optimum power assignment ratio, R_{opt}, is 1.0. This means that it is the best system to send base information by QPSK in this range, because receiver cannot get refinement information. In this case, system keep the spectral efficiency to nearly two until C/N below 15 dB. On the other hand, at the range of $C/N > 23.4$ dB, R_{opt} is nearly 0.8, and the spectral efficiency is grow with C/N to six, because receiver can get base and refinement information.

5. Conclusions

In this paper, we have analyzed the performance of the hierarchical transmission scheme for 21 GHz digital HDTV broadcasting satellite system in the presence of the rainfall attenuation. We assumed two hierarchical modulation systems, and analyzed the relation between power assignment ratio and system performances. It is shown that, when we transmit digital hierarchical information to realize the "*Graceful Degradation*", there is a optimum power assignment ratio, i.e., $R = 0.82$ in embedding 16 QAM system and $R = 0.80$ in embedding 64 QAM system. And we also clarify that, this optimum ratio is varied with the measure of system performance. So there is a needs of optimization by subjective evaluation, because it gives the total broadcasting quality for a viewer.

Acknowledgements

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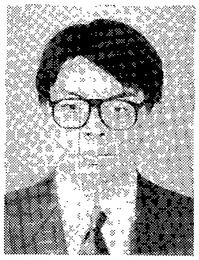

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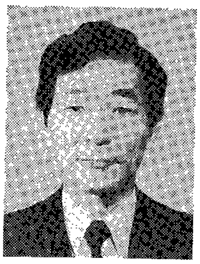

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