Iterative V-BLAST Decoding Algorithm in the AMC System with a STD Scheme

Keun-Hong Lee, Sang-Jin Ryoo, Seo-Gyun Kim, and In-Tae Hwang, *Member, KIMICS*

Abstract—In this paper, we propose and analyze the AMC (Adaptive Modulation and Coding) system with efficient turbo coded V-BLAST (Vertical-Bell-lab Layered Space-Time) technique. The proposed algorithm adopts extrinsic information from a MAP (Maximum A Posteriori) decoder with iterative decoding as a priori probability in two decoding procedures of V-BLAST scheme; the ordering and the slicing. Also, we consider the AMC system using the conventional turbo coded V-BLAST technique that simply combines the V-BLAST scheme with the turbo coding scheme. And we compare the proposed decoding algorithm to a conventional V-BLAST decoding algorithm and a ML (Maximum Likelihood) decoding algorithm. In addition, we apply a STD (Selection Transmit Diversity) scheme to the systems for better performance improvement. Results indicate that the proposed systems achieve better throughput performance than the conventional systems over the entire SNR range. In terms of transmission rate performance, the suggested system is close in proximity to the conventional system using the ML decoding algorithm.

Index Terms— *AMC, STD, V-BLAST, MAP Decoder, Iterative decoding*

I. INTRODUCTION

In the next generation mobile communication systems, data throughput performance improvement will be a hot issue. In order to fulfill the need for an ultra-high speed service, active researches on MIMO systems have been in progress. Generally, in MIMO systems, the main schemes considered are the MIMO diversity scheme and the MIMO multiplexing scheme [1][2]. Also, in order to improve the throughput performance, together with MIMO system, an AMC scheme has drawn much attention as a pioneer of the next generation mobile communication systems [3].

Considering the complexity of the scheme of MIMO system combined with AMC scheme, this paper explores the V-BLAST scheme and turbo coding scheme [4][5]. The turbo coding scheme with iterative decoding implies parallel concatenated recursive systematic convolutional codes, and is iteratively decoded using APP (a posteriori probabilities) algorithms for the constituent codes [6]. We will present the performance analysis of the AMC systems with several turbo coded V-BLAST techniques. As a method for better performance improvement, we will then consider a 4-2x2 MIMO scheme applying the STD scheme that selects 2 antennas from 4 transmission antennas [7].

II. The AMC SYSTEM WITH EFFICIENT TURBO CODED V-BLAST TECHNIQUE

Figure 1 shows the transmitter and receiver structure of the system applied the proposed decoding algorithm. The difference with the AMC system using the conventional turbo coded V-BLAST technique that is simply combined the V-BLAST scheme with the turbo coding scheme is that in the proposed system, the extrinsic information from a MAP decoder as an a priori probability in the ordering and slicing decoding procedures of a V-BLAST scheme in an AMC system [8][9]. That is, it is the difference that the ordering and slicing of V-BLAST decoding procedure are modified by using the extrinsic information. This scheme operates iteratively and is defined as the main MAP iteration.

Also, whenever it operates internally, an iterative decoding of MAP decoder is performed and this method is defined as the sub MAP iteration. Many researchers, such as Hochwald/Brink [10], Hassibi [11], Baro [12], Bhargave [4], and Gianakis [13], have been actively developing such iterative decoding algorithm.

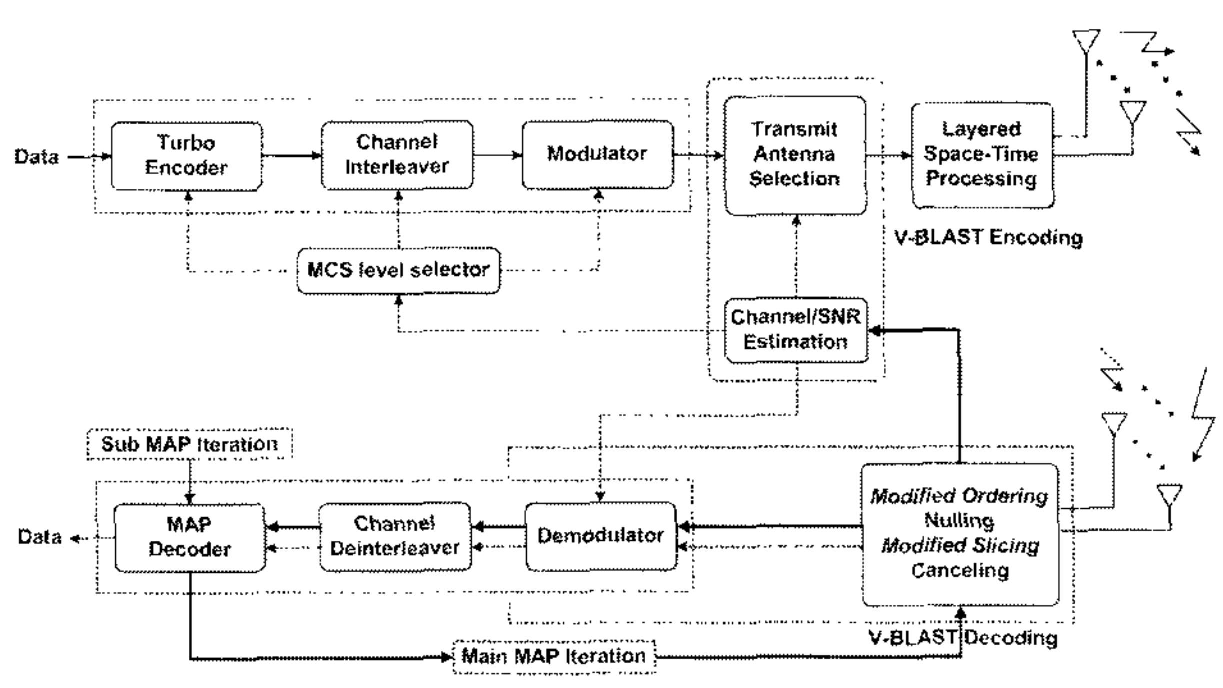

Fig. 1 Transmitter and receiver structure of the AMC system with efficient turbo coded V-BLAST technique

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We propose iterative decoding algorithm that has a better performance and a lower complexity for applying to the practical system.

In this proposed system, let us consider a system equipped with M transmission antennas and N reception antennas. We further assume that each transmission channel is modeled as a flat Rayleigh fading channel. The received signal in the V-BLAST receiver is denoted by

$$\boldsymbol{X} = \boldsymbol{H}s + \boldsymbol{n} \tag{1}$$

where $\boldsymbol{X} = [x_1,\cdots,x_N]^T$ is the received signal vector, $s = [s_1,\cdots,s_M]^T$ is the transmitted symbol vector, $\boldsymbol{H}$ is the $N\times M$ channel matrix, $\boldsymbol{n} = [n_1,\cdots,n_N]^T$ is the noise vector, the superscript T signifies the transpose matrix, and the noise vector, $\boldsymbol{n}$, is modeled as a flat Rayleigh fading noise. In addition, s_m is the 2^Q-ary modulated symbol; that is $s_m = f(d_1^m,\cdots,d_Q^m) \in \Phi=\{\varphi_1,\cdots,\varphi_{2^Q}\}$, where Q denotes the bit number per symbol, $f(\cdot)$ denotes the symbol modulation function, $\{d_q^m\}_{q=1,\cdots,Q}$ represents the q-th information bits that correspond to s_m, and $\{\varphi_i\}_{i=1,\cdots,2^Q}$ represents the i-th symbol. The proposed slicing algorithm does not make a hard decision with the received signal but makes a decision with the extrinsic information from the MAP decoder. This extrinsic information from the MAP decoder is the log-likelihood function, which can be described as

$$L_{m,q} = \log\frac{p\left(d_q^m = 1\right)}{p\left(d_q^m = 0\right)} \tag{2}$$

where $L_{m,q}$ is the extrinsic information that corresponds to d_q^m. Specifically, $\{d_q^m\}_{q=1,\dots,Q}$ is determined by $\{L_{m,q}\}_{q=1,\dots,Q}$, respectively. (e.g., if $L_{m,q}$ is greater than 0, d_q^m is determined to be 1. Otherwise, d_q^m is determined to be 0.) The proposed slicing algorithm then performs the quantization operation appropriate to the constellation in use corresponding to $\{d_q^m\}_{q=1,\dots,Q}$. In a conventional V-BLAST ordering procedure, the decoding order is determined by the SNR of the corresponding layer. The conventional V-BLAST ordering is described as

$$l_k = \arg\min_m \| \left(H_k^+\right)_m \|^2 \tag{3}$$

where k denotes the decoding stage and the superscript † represents the pseudo-inverse matrix. The SNR is a function of the channel power, and the layer with the largest channel power is the first layer that is decoded. A high SNR signifies a low symbol error rate. From this fact, it follows that the maximum SNR criterion can be considered to be a specific version of the minimum symbol error criterion. The proposed ordering algorithm is a function not only of the SNR but also of the extrinsic information. It can be modified accordingly to

$$l_k = \arg\min_m P_m(e \mid X_k, H_k, L_m^{(i)}) \tag{4}$$

where $P_m(e|X_k, H_k, L_m^{(i)})$ is the symbol error probability of the m-th layer and $L_m^{(i)}=[L_{m,1}^{(i)},\cdots,L_{m,Q}^{(i)}]^T$ is the extrinsic information vector of the l_k-th layer at the i-th main MAP iteration. The symbol error probability, P_m, can be calculated from

$$P_m(e|X_k,H_k,L_m^{(i)}) = \frac{1}{2^Q}\sum_{q=1}^{2^Q}\sum_{p=1,p\neq q}^{2^Q} P(\varphi_q|L_m^{(i)})P(\varphi_q \to \varphi_p|X_k,H_k,L_m^{(i)}) \tag{5}$$

where φ_q is the original transmitted symbol, φ_p is the possible symbol excluding the original transmitted symbol (φ_q), and $P(\varphi_q \to \varphi_p|X_k, H_k, L_m^{(i)})$ is the pair-wise symbol error probability, which can be obtained from

$$\begin{aligned} &P\{\varphi_q \to \varphi_p \mid X_k, H_k, L_m^{(i)}\} \\ &= P\{p(\varphi_q \mid y_m) < p(\varphi_p \mid y_m)\} \\ &= P\{\log p(\varphi_q \mid y_m) < \log p(\varphi_p \mid y_m)\} \end{aligned} \tag{6}$$

where y_m is the desired symbol that deletes the interference of other symbols after the nulling process of the V-BLAST decoding in the received symbol of the m-th layer, x_m. With the assumption that the variance of noise corresponding to the m-th layer is $\sigma_m^2/2$, in equation (6), the log posteriori function of φ_p is described by

$$\begin{aligned} \log p(\varphi_p \mid y_m) &= \log\frac{p(\varphi_p \mid L_m^{(i)})p(y_m \mid \varphi_p)}{p(y_m)} \\ &= \log p(\varphi_p \mid L_m^{(i)}) + \frac{\mathrm{Re}\{(\varphi_p - \varphi_q)(2y_m - (\varphi_p + \varphi_q))^*\}}{2\sigma_m^2} \end{aligned} \tag{7}$$

where the superscript * signifies a complex conjugate.

III. SIMULATION RESULTS

A. MCS level and simulation parameters

Tables 1 and 2 show the MCS (Modulation and Coding Scheme) level selection thresholds and simulation parameters, respectively. The detailed parameters in Table 1 are established based on the 1X EV-DO Standards [14]. There are many references in the selection of the MCS level selection threshold. For example, the threshold can be selected to satisfy the required BER and FER (Frame Error Rate). Because we have put more emphasis on the data transmission rate, we selected the threshold that maximizes the throughput performance. That is, the threshold of the selected MCS level is gained from the MCS level transmission rate performance intersection in each system.

One frame is set up with one transmission slot and the frame length is 2,048 symbols. If one bit error occurs in one frame, we take it as a frame error. When frame error does not occur, the transmission rate is calculated in accordance with V-BLAST technique by the order of "bit length × data rate × number of transmit antenna." The performance of transmission rate closely corresponds to the capacity of FER. So in accordance with transmission rate, performance analysis is obtained by error probability.

Table 1 MCS level

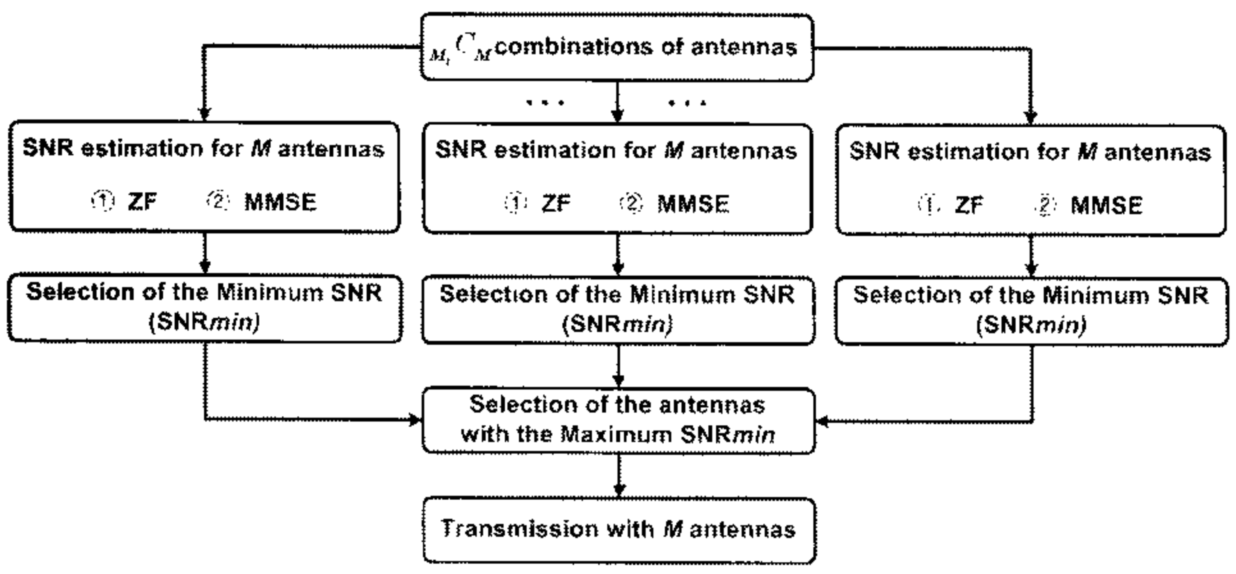
MCS level	Data rate (Kbps)	Number of bits per frame	Code rate	Modulation
1	614.4	1,024	1/3	QPSK
2	1,228.8	2,048	2/3	QPSK
3	1,843.2	3,072	2/3	8PSK
4	2,457.6	2,096	2/3	16QAM

Table 2 Simulation parameters

Parameter	Value
Turbo-coding scheme	PCCC
MAP iteration of the AMC system with a conventional V-BLAST technique	4
Main MAP iteration of the AMC system with the proposed V-BLAST technique	4
Sub MAP iteration of the AMC system with the proposed V-BLAST technique	2
Channel	Flat fading

B. The transmitter antenna selection algorithm in MIMO systems

Figure 2 shows the transmitter antenna selection algorithm when the STD scheme is applied to the AMC system with the proposed V-BLAST technique [15][16]. The SNR for each layer was computed after the nulling. For example, if there are three possible antenna combinations, we compare the minimum SNR values of each combination. First, we transmit a signal by using an antenna combination that has the maximum SNR value of the minimum SNR values of each combination. Hence, for the V-BLAST processing, we use the antenna combination that has the maximum SNR value of the minimum SNR values in each combination.



① ZF : $SNR_k = \dfrac{E_S}{MN_0[\mathbf{H}_{sub}^{*}\mathbf{H}_{sub}]^{-1}_{kk}}$

② MMSE : $SNR_k = \dfrac{E_S}{MN_0[\mathbf{H}_{sub}^{*}\mathbf{H}_{sub} + MN_0 / E_S \mathbf{I}_M]^{-1}_{kk}} - 1$

Fig. 2 The transmit antenna selection algorithm in the MIMO schemes

C. Complexity of each decoding algorithm in AMC systems with several turbo coded V-BLAST Techniques

In section, we have considered the complexity of the proposed decoding algorithm, the conventional V-BLAST decoding algorithm, and the ML decoding algorithm in the AMC systems with several turbo coded V-BLAST techniques.

Multiplication operations contribute to the complexity of implementing the system in actuality. Each decoding algorithm is compared to the number of multiplication operations in Table 3 [17]. In this table, C is the number of symbols, S is the number of sub MAP iterations, L is the number of main MAP iterations, and B is the number of bits per symbol. The table shows that the proposed decoding algorithm is more complex than the conventional V-BLAST decoding algorithm, but is less complex than the ML decoding algorithm. Particularly, the proposed decoding algorithm is relatively less complex than the ML decoding algorithm when it is used with a higher order modulation and more transmission and reception antennas.

According to the table, as the modulation changes from QPSK to 16QAM in the case of M=N=4, the computational complexity of the proposed decoding algorithm is about 24% to 0.1% of that of the ML decoding algorithm. Furthermore, comparing with the complexity of the proposed scheme in [17], the complexity of our proposed scheme is relatively less complex for N=M=4, QPSK and L=3 or 4.

Table 3 Complexity of each decoding algorithm (L=4, S=2, M=N=4)

	ML decoding	Conventional decoding	Proposed decoding
Required multiplications	$C^M(M+1)N$	$(M+1)N^3+$ $(3/2)M^2N+$ $[(7/2)M-1]N-1$	$(M+1)N^3+$ $L[M^2N(B+1)+$ $(3M-1)N-1]$
QPSK	5,120	467	1,260
8PSK	81,920	467	1,516
16QAM	1,310,720	467	1,772

D. Performance of the AMC systems with several turbo coded V-BLAST techniques

Figure 3 shows the throughputs of each decoding algorithm in the AMC systems with several turbo coded V-BLAST techniques in a 2x2 MIMO scheme using 2 transmission and reception antennas. We can see that the proposed systems achieve better throughput performance than the conventional systems over the entire SNR range. Specifically, we can see that the proposed system has throughput improvement of more 300 kbps between 7 dB ~ 15 dB SNR. And the proposed system at 11 dB SNR shows that the throughput improvement is about 350 kbps. Further, the proposed system is close to the existing ML decoding system in terms of the performance of transmission rate.

Figure 4 shows the throughputs of the AMC systems with several turbo coded V-BLAST techniques in a 2x2 MIMO scheme and a 4-2x2 MIMO scheme. We can see that the systems in a 4-2x2 MIMO scheme achieve better throughput performance than others. The systems in the

4-2x2 MIMO scheme applying STD, improve the SNR through the selection diversity gain. This leads to a reduced error rate and an increment in the probability to select the MCS level with a higher data rate. Accordingly, they achieve a greater throughput performance than others.

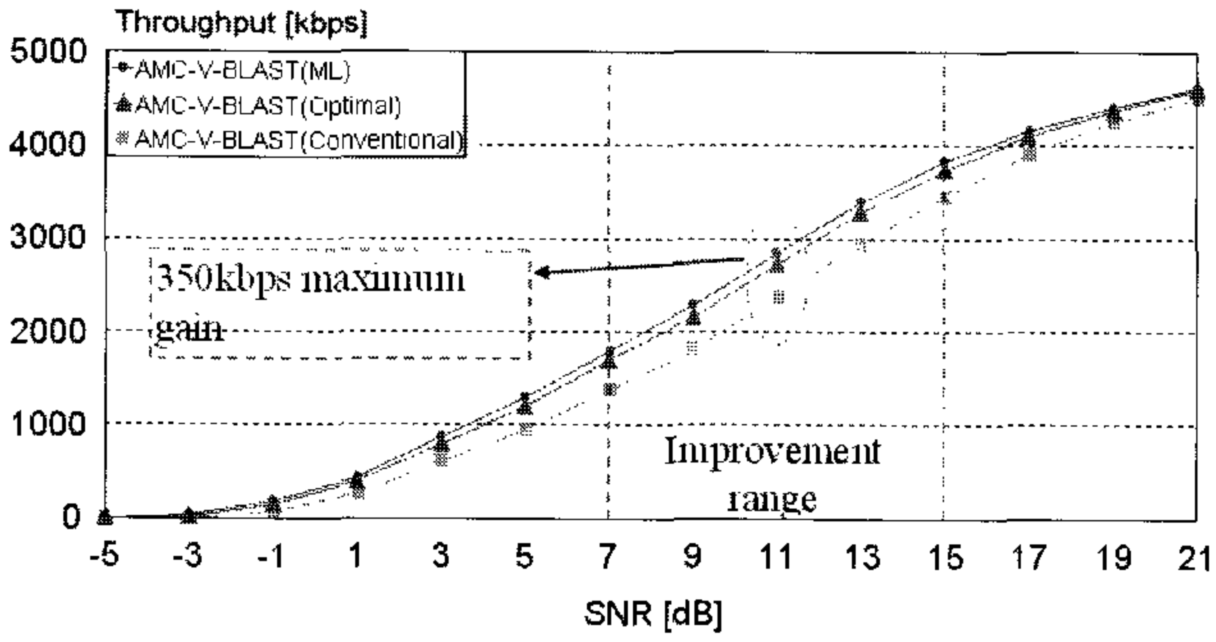


Fig. 3 Throughputs of each decoding algorithm in the AMC systems with several turbo coded V-BLAST techniques in a 2x2 MIMO scheme

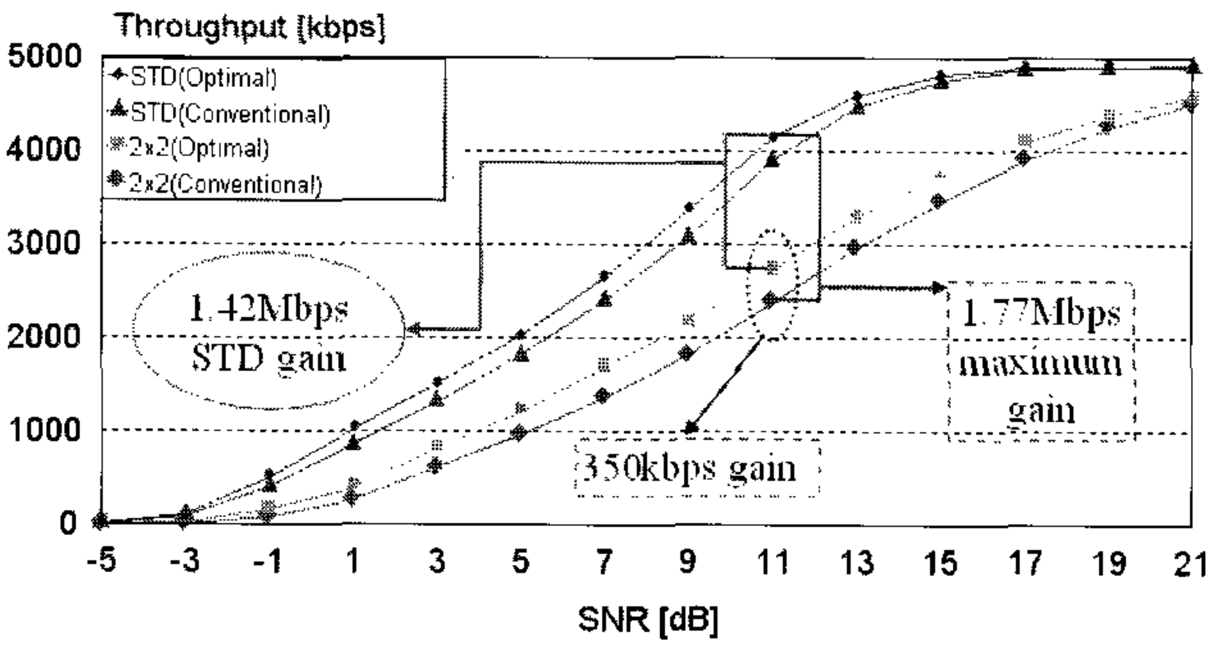


Fig. 4 Throughputs of the AMC systems with several turbo coded V-BLAST techniques in a 2x2 MIMO scheme and a 4-2x2 MIMO scheme

IV. CONCLUSIONS

We have proposed an AMC system with efficient turbo coded V-BLAST technique that adopts the extrinsic information from a MAP decoder with iterative decoding as an a priori probability in two decoding procedures of V-BLAST; the ordering and the slicing. We have considered the system with conventional turbo coded V-BLAST technique that is simply combined V-BLAST scheme with turbo coding scheme.

With the result of performance comparison of the proposed decoding algorithm, the conventional V-BLAST decoding algorithm, and the ML decoding algorithm in AMC system with several turbo coded V-BLAST techniques, we can say that the proposed system is less complex than the existing ML decoding system while there is little difference in their performance of transmission rate. Also, the complexity of the proposed system is higher than that of the conventional system; however, the performance improvement is also significant. The proposed system achieves a superior throughput performance than the conventional system the entire SNR range. In addition, the simulation results show that the throughput improvement in a 2x2 MIMO scheme is about 350 kbps. Specifically, when we consider the proposed system, the difference of throughput performance between a 2x2 MIMO scheme and a 4-2x2 MIMO scheme is about 1.42 Mbps at 11 dB SNR. In addition, the result shows that the proposed system in a 4-2x2 MIMO scheme achieves a superior the throughput performance than the conventional system in a 2x2 MIMO scheme. It particularly shows that the maximum throughput improvement is about 1.77 Mbps at 11 dB SNR.

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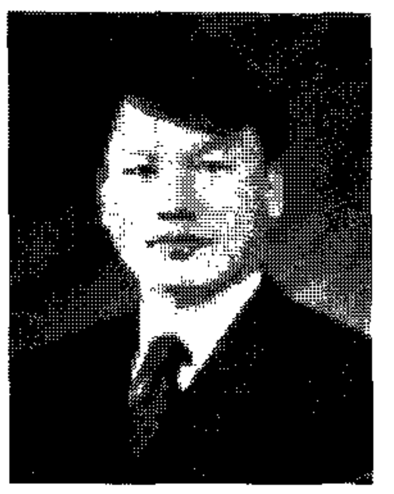

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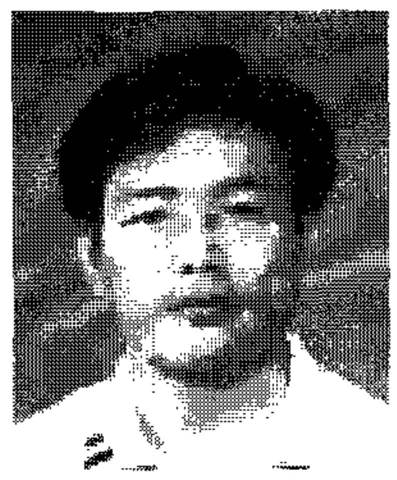

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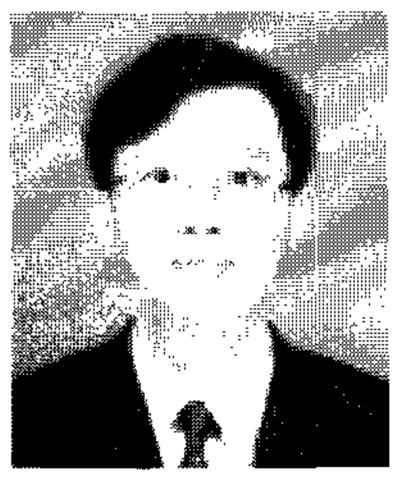

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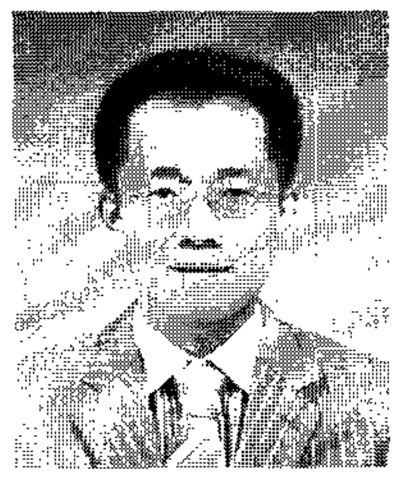

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