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Physical Layer Design of W-CDMA IMT-2000 System and Performance Analysis of Key Characteristics

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ABSTRACT

In this paper, the physical layer design of IMT-2000 system being developed by SK Telecom is introduced. The outband signaling scheme and the two-pilot scheme are adopted for multimedia service and inter-cell asynchronous mode respectively. In addition, the synchronous transmission scheme is proposed to reduce the interference in the reverse link. The algorithm and simulation results of 'two-pilot scheme' for inter-cell asynchronous mode and 'reverse synchronous control' for synchronous transmission are presented.

I. Introduction

The communications system based on W-CDMA technologies has been known as the most promising candidate for the IMT-2000[1][2]. SK Telecom, the largest CDMA cellular service provider in the world, has been developing its own W-CDMA system as the IMT-2000 candidate to provide subscribers with various services in multimedia environment. We think that the differentiation from the 2nd Generation service is the most important key factor to success for IMT-2000 in Korea, because the 2nd Generation service launched in 1996 is not proper to satisfy the desire to communicate multimedia information in mobile environment. For the differentiation, we consider the followings as our view on IMT-2000;

(1) Significantly higher voice quality than the 2nd Generation system because the voice service may be the most popular application in mobile communication.

(2) Wide range of voice and non-voice services including packet data and multimedia service because the 2nd Generation system mainly provides voice service.

(3) Wide range of user density and coverage because the 2nd Generation system does not work well in underground or indoor region.

(4) Improved ease of operation and flexible architecture to accommodate advanced technique.

(5) High degree of commonality of design worldwide.

To meet the technical requirements related to our view, several key technologies are employed in our radio interface design. It corresponds to the key characteristics of our system as follows;

(1) Wideband spreading and multi-code scheme are employed to provide high data rate capability.

(2) We choose coherent demodulation with pilot channel and fast power control in both links to provide high quality services.

(3) Inter-cell asynchronous mode is adopted to improve the ease of operation/deployment and wide coverage.

(4) Multi-bandwidth spreading and packet data services are considered and the associated control chan-

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nel is reinforced to support multimedia and flexible radio bearer.

(5) We adopt outband signaling and the rate information of traffic is carried by the outband signaling channel, because the required bit error rate and delay constraint are different due to the various characteristics in information source.

Table 1. shows key features of SK Telecom IMT-2000 system.

Table 1. Key feature of SK Telecom IMT-2000

Channel spacing		1.25/5/20 MHz
Chip rate		1.024/4.096/16.384 Mcps
Frame length		10msec
Channel structure	DL	pilot, synch, paging, traffic, signaling, packet control, packet traffic
	UL	pilot/signaling, access, traffic, packet control, packet traffic
Detection scheme		Coherent with pilot ch.
Multi-rate		Variable spreading & multi-code
Rate information		Carried by signaling ch.
Rate matching		Repetition & Puncturing
Channel coding		Convolutional coding(1/2, K=9) + RS code
Power control	DL	Closed loop (1kbps)
	UL	Open & Closed loop (2kbps)
Modulation /spreading	DL	QPSK/QPSK
	UL	QPSK/QPSK
Synchronization between cells		Asynchronous scheme with 'two pilot scheme'
Inter-MS synchronization in the reverse link		Synchronous

This paper presents the overview of basic concept of SK Telecom IMT-2000 system and the performance with emphasis on the inter-cell asynchronous mode and synchronous transmission scheme in the reverse link.

The channel structures are introduced in chapter Ⅱ and chapter Ⅲ provides the concept of the inter-cell asynchronous mode and the synchronous transmission algorithm in the reverse link. The simulation results are given in chapter Ⅳ and finally conclusion is presented in chapter Ⅴ.

Ⅱ. Channel Structure

The forward link channel consists of the cluster pilot, cell pilot, synch, paging, signaling and traffic channel. For the rapid acquisition in inter-cell asynchronous mode, each base station transmits two pilot signals, cluster pilot and cell pilot. The traffic and signaling channel are dedicated to a mobile station and the power control bit is carried by signaling channel. Fig 1 shows the traffic and signaling channel structure in the forward link.

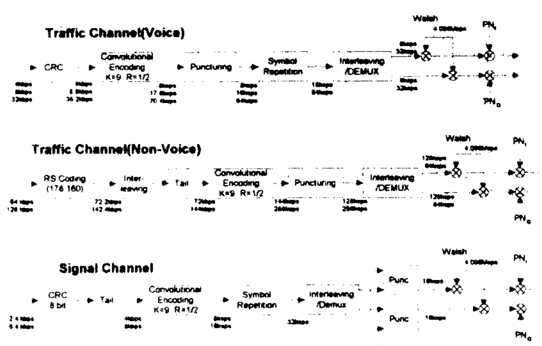

Fig. 1 Traffic and signaling channel structure in the forward link

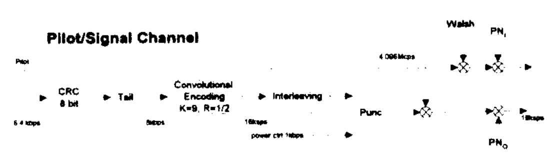

Fig. 2 Pilot/Signaling channel structure in the reverse link

The reverse link channels are classified into the pilot, access, signaling and traffic channel. To reduce the amplitude fluctuation in transmitting signal, the pilot and signaling are combined, complex spread and transmitted as shown in Fig. 2.

Ⅲ. Key Characteristics of SK Telecom IMT-2000 System

1. Two pilot scheme for inter-cell asynchronous mode

For precise inter-cell synchronization, each cell site requires high-cost equipment such as global positioning system(GPS) and rubidium backup oscillators. Moreover, it is difficult to deploy GPS in the hard-to-reach location such as basement and it is desirable that the radio network is operated independently of the external time base systems. Considering these factors, SK Telecom adopts the inter-cell asynchronous mode.

In inter-cell synchronous mode such as IS-95, cells are distinguished by the phase offset of one PN code and mobile stations are able to acquire the pilot channel by searching the phase offset of only one PN code. In inter-cell asynchronous mode, however, cells should be distinguished by its own PN codes generated by different polynomials, not by the PN phase offset. In an initial state, the mobile station searches all PN codes with various phases, consequently the uncertainty region corresponds to the number of PN codes times the number of PN phases. The two-pilot scheme has been devised by SK Telecom to reduce a burden of pilot acquisition time in inter-cell asynchronous mode. Each cell is identified by a unique PN code generated by different polynomials and several cells are tied into a cluster as shown in Fig. 3. There are no special restrictions on determining the number of clusters and cells, only if the given numbers guarantee reasonable time consumption in acquisition of pilot channel and handoff procedure.

Each cell transmits two pilots, cell pilot and cluster pilot as shown in Fig. 4.

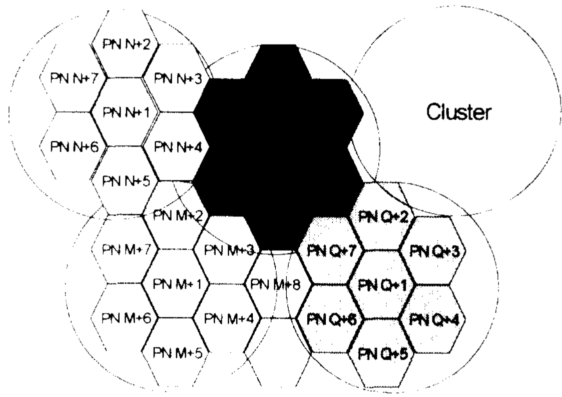

Fig. 3 Cell configuration

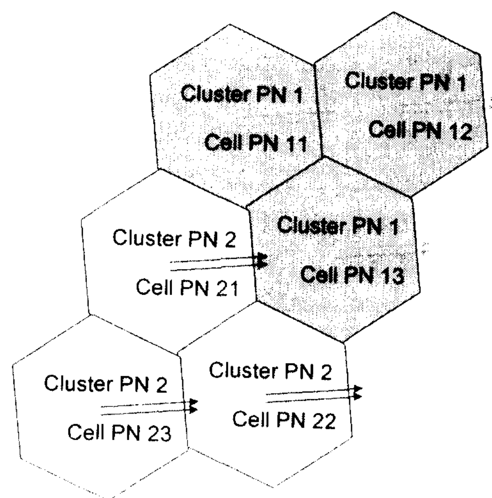

Fig. 4 Two-Pilot Scheme

Each cell pilot signal is spread by different PN codes and all the cluster pilot signals within a cluster are spread by the same PN code. The acquisition is carried out by two steps, identifying the cluster that the mobile station belongs to and searching the cell pilot. The first step is acquiring the cluster pilot channel and the class of cell pilot code is identified by the cluster pilot. In the second step, the mobile station searches all cell pilot signals in the class and obtains initial system synchronization.

Compared with searching cell pilots only, the two pilot scheme reduces dramatically the acquisition time in inter-cell asynchronous mode. If the total number of cell PN codes that a mobile station should search is assumed to be 512 and the number of clusters is 16, the mobile station searches only 16 cluster PN codes and 32(512/16) cell PN codes instead of 512 cell PN codes. In addition, our system can carry out rapid cell search with the PN code phase information obtained from a cluster pilot because the cluster and cell pilot signals are synchronized. From a point of hardware implementation, The complexity of searcher part in the modem increases about two times due to the two pilot scheme.

2. Channel Synchronization In The Reverse Link

It is well known that the capacity of DS-CDMA system is mainly limited by the Multiple Access Interference(MAI), especially in the reverse link due to the absence of orthogonality among the signals from mobile stations(MS's). DS-CDMA based system allows each user to share the same frequency band and each user is identified with the spreading code. When the signal transmitted by a specific user is demodulated, the signals from other users are regarded as interference. This kind of interference is classified as the intra-cell interference generated by other channels within a cell and the inter-cell interference produced by neighboring cells. In this paper, only the intra-cell interference is considered, because intra-cell interference is a dominant factor in determining the channel capacity in the reverse link.

In the forward link, identifying MS's with orthogonal code[3] can reduce the intra-cell interference. All the forward channels from a base station are multiplied by codes and transmitted simultaneously, so the orthogonality among channels is valid. However, in the reverse link, the current DS-CDMA system generally adopts the inter-MS asynchronous transmission because time delays among the reverse channels are different due to the random geographical distribution of MS's. Therefore, the interference cannot be reduced with the orthogonal property even though the Walsh codes are multiplied. Several methods are introduced to reduce the interference in the reverse link [4]. We propose the scheme to adjust the transmission timing in each mobile station. The idea to control the transmission time was proposed in other CDMA, TDMA mobile systems, but it is difficult to maintain the transmission timing with stability in case the mobile stations move fast or the propagation paths to a base station vary rapidly.

We propose to use closed loop timing control, where the reverse channels are identified with Walsh codes and the synchronization among the channel signals arriving at the base station(BS) is achieved by timing control in a manner similar to power control. That is, BS estimates the difference between the reference clock and the clock synchronized with the signal from a MS, then transmits the timing control bit to order MS to "advance or delay" its transmission time. Each MS adjusts its transmission time according to the control bit received from the BS by timing control step (1/4 chip). Notably, this scheme does not mean that it is a substitute for the conventional tracking loop. During the timing control procedure, the tracking loop should be operated continuously to synchronize its local PN code timing with the received one.

The timing control process for the synchronization is carried out only for the main path. Although the synchronization between main paths is accomplished, the interference due to multipaths still exists. It is impossible to carry out synchronization between users' multipaths, but the performance improvement can be achieved because the main path occupies more than half of the total received signal power[5].

The performance of the synchronous transmission was evaluated in comparison with the asynchronous transmission in the previous paper[6]. These results showed that the synchronous transmission gives about 3dB better performance than the asynchronous transmission when the difference of the arrival time among channels is kept less than 1/4 chip. However, channel conditions change in the mobile environment as each user moves and even the paths disappear due to the shadowing effect. Therefore, the delay of the channel signals from each MS to a BS is not maintained constantly, so the timing control process should overcome this kind of variation continuously to achieve synchronization between main paths. The variation of the delay due to the change of the channel environment was not considered in the previous paper. This kind of variation is considered by changing the delay parameter of each received signal in a random manner. Various timing control rate is evaluated to reduce MAI less than the asynchronous transmission under such an environment.

2.1 Timing control algorithm

As introduced in the above, a base station continuously controls each mobile station's transmission time to synchronize the arrival time of reverse channel signals with the reference clock generated in the base station.

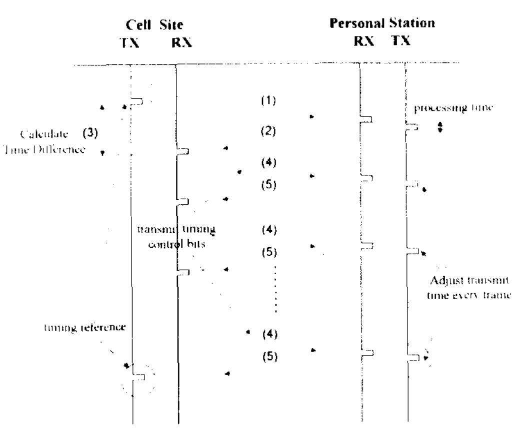

Fig. 5 The procedure of reverse synchronization

Fig. 5 shows the procedure of the timing control. The numbers in the round brackets denote the following processes:

(1) Forward channels are transmitted to each MS.

(2) Each MS carries out acquisition and tracking, and transmits the reverse channel signals to the BS.

(3) BS estimates the time difference between timing reference clock which is periodically generated in BS and the frame clock acquired from the received signal.

(4) BS decides to delay or advance MS's transmission time and generates the timing control bit, which is inserted in the forward channel by puncturing.

(5) The reverse channel signals are either advanced or delayed by 1/4 chip according to the received control bit.

(6) Repeat step (3)~(5) until the frame clocks from all reverse channels are synchronized with the reference clock.

2.2 Analytical model

When the BPSK spreading is assumed for simplicity, the received signal is written as follows.

$$r(t)=\sum_{n=1}^{M} x_n(t-\tau_{n,k})+N(t)$$

where M and L denote the number of users and multipath, respectively.

$x_n(t-\tau_{n,k})$ is the k-th multipath component of the signal transmitted by the n-th MS and given by

$$x_n(t-\tau_{n,k})=\alpha_{n,k}d_n(t-\tau_{n,k})p(t-\tau_{n,k})W_n(t-\tau_{n,k})$$

$\alpha_{n,k}$	The channel gain for k-th path in n-th user
$d_n(t)$	Binary data signal transmitted by the n-th user
$p(t)$	PN(Pseudo Noise) sequence for the spreading
$W_n(t)$	Walsh code allocated to n-th user
$\tau_{n,k}$	Delay of the k-th path in n-th user

When the l-th path is assumed to be a main path of the n-th MS, $\tau_{n,l}$ can be expressed by $\tau_{n,l}=\tau'_{n,l}+\tau_{refer}$, where τ_{refer} is the delay which all reverse channels should have in order to be synchronized with the reference clock. Each MS's time offset $\tau'_{n,l}$ is reduced to be zero, when the synchronization in the reverse link is achieved. If the l-th path from the m-th user is demodulated, r(t) is despread by $p(t-\tau_{m,l})W_m(t-\tau_{m,l})$

and integrated during one symbol period, T. The decision variable d_m is expressed as follows.

$$d_m = \pm \alpha_{m,l} T + I^{self} + I^{other} + I^{noise}$$

$$I^{self} = \int_T \sum_{k=1, \neq l}^{L} \alpha_{m,k} d_m(t-\tau_{m,k})\, p(t-\tau_{m,k})\, p(t-\tau_{m,l})\, W_m(t-\tau_{m,k})\, W_m(t-\tau_{m,l})\, dt$$

$$I^{other} = \int_T \sum_{n=1, \neq m}^{M} \sum_{k=1}^{L} \alpha_{n,k} d_n(t-\tau_{n,k})\, p(t-\tau_{n,k})\, p(t-\tau_{m,l})\, W_n(t-\tau_{n,k})\, W_m(t-\tau_{m,l})\, dt$$

where I^{noise} is the additive Gaussian noise term.

The variation of the arrival time in the reverse channel is considered by changing the delay variables of each user's signal in a random manner shown in Fig 6.

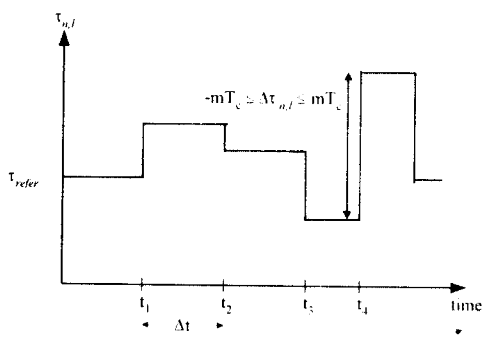

Fig. 6 The variation of the main paths' delay variables

The channel variation interval Δt and the increment of the delay value, $\Delta\tau_{n,k}$ are handled as random variables that have the following probability distribution.

$$p(\Delta t) = 1/\Delta t_{avg}, \quad \Delta t_{avg}/2 < \Delta t < 3\Delta t_{avg}/2$$
$$= 0, \quad \text{otherwise}$$
$$p(\Delta\tau') = 1/(2mT_c), \quad -mT_c < \Delta\tau' < mT_c$$
$$= 0, \quad \text{otherwise}$$

where Tc denotes the one chip period and Δt_{avg} means the average period during which the delay parameters $\tau_{n,k}$ are increased or decreased and the maximum increment of the delay variables is m chips.

We present the simulation results in chapter Ⅳ, assuming that the increment is in the range of one and two chips. BS estimates the time difference between the reference clock and the clock acquired from the received signal and transmits the timing control bit to advance or delay transmission time of the MS. The delay parameters are adjusted as follows.

If $\tau_{n,l} \geq \tau_{refer}$

$$\tau_{n,l} = \tau_{n,l} + T_c/4$$

else

$$\tau_{n,l} = \tau_{n,l} - T_c/4$$

for all n.

In addition, we introduce the parameter N representing the ratio of the timing control rate to the average channel variation rate. If Δt_{avg} is 100 ms and N is 4, the timing control process is carried out every 25ms.

Ⅳ. Simulation Results

1. Two Pilot Scheme

Table 2 shows the simulation parameters. The simulation has been carried out under the 19 hexagonal cell layout. The sum of cluster and cell pilot

Table 2. Simulation Parameter

Radio Link Parameter		
Chip rate		4.096Mcps
Spreading Code	Cluster	Gold code (2048 chips)
	cell pilot	ML code(40960) + Walsh 0(128)
	cell traffic	ML code(40960) + Walsh j(128)
Total # of cell pilot code		512(32 × 16 clusters)
Modulation	Data	QPSK
	Spreading	QPSK
Propagation path loss model		
Path loss decay factor		3.8
Random loss		Log-normal, ? = 10dB
Multi-path fading		6 paths Rayleigh (ITU-R TG 8/1 Veh.B) f_D = 64Hz

power is 25% of the total power in a cell and this value corresponds to the practical operating power ratio in IS-95. For rapid acquisition, 32 parallel sliding correlators are used. Fig. 7 shows the simulation results of cell search time distribution in a cell and the percentage of the correct search versus cell search time is shown in Fig. 8.

As shown in Fig. 7 and 8, the percentage that cell search is accomplished in less than 200 msec is about 90%.

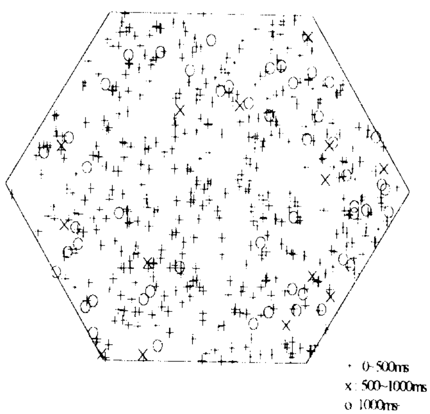

Fig. 7 Cell search time distribution in a cell

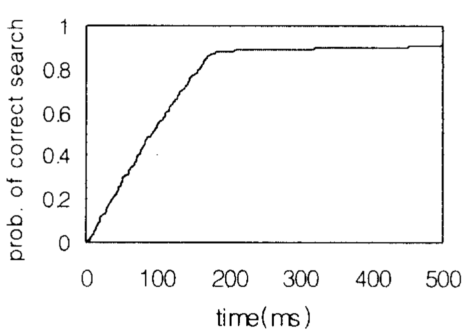

Fig. 8 Cumulative density function of cell search time

2. Channel Synch. In The Reverse Link

The vehicular B of ITU-R TG 8/1 channel model is adopted in this simulation. The carrier frequency and vehicle velocity are assumed to be 1.9 GHz and 20 km/h. Each path delay and power is listed in table 3.

Table 3. IMT-2000 TG 8/1 vehicular channel model

Delay(ns)	Power(dB)
0	0.0
310	−1.0
710	−9.0
1090	−10.0
1730	−15.0
2510	−20.0

In the synchronous transmission, 128-ary Walsh orthogonal code is used for identifying each MS and maximal length PN code of length 2^{15} is used for spreading. In the asynchronous transmission, each MS is identified with PN code phase offsets.

Fig. 9 shows the amount of multiple access interference(MAI) on dB scale according to the number of users, when the ratio parameter N is 1, 2, 3, 4, 8 and 12. The step size of timing control is 1/4 chip and the maximum increment of delay variables is one chip. Synchronous transmission gives about 3 dB better performance than the asynchronous one irrespective of the number of users when N exceeds 3. However, when N is 1 or 2, the performance improvement of the synchronous transmission is less than 1 dB and its effect is negligible. In addition, if the ratio of the timing control rate to the channel variation rate is above 3, the performance improvement is not notable in spite of increasing the value of N.

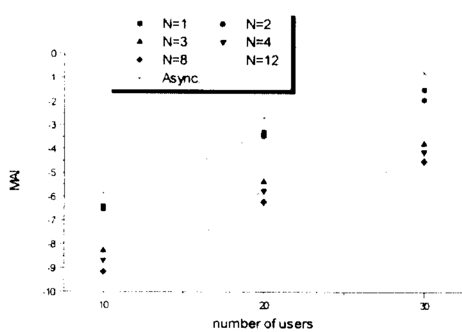

Fig. 9 MAI versus the number of users

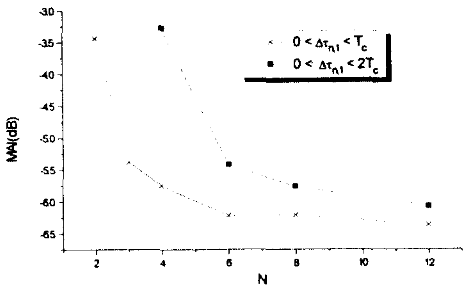

Fig. 10 MAI versus ratio paramter, N

Fig. 10 shows the results obtained assuming two different range of the delay variation. Larger increment of the variable means that there is a abrupt change of the delay variables. Each curve in that figure represents the amount of the MAI on the dB scale according to the ratio parameter N of the timing control rate to the channel variation rate. Here, the range of delay variation is less than 1 chip and 2 chips, respectively. When the channel environment changes more abruptly, almost the same performance can be achieved by increasing the control rate.

As shown in the simulation, the overhead of the proposed algorithm depends on the variation of misalignment, which is a function of mobile speed, frequency and environment. But it is observed that the average period of delay profile variation is usually less than ±1 chip in 1000 ms[7], which requires very long period of closed loop timing control.

V. Conclusion

We have introduced the basic requirements for designing the radio interface for IMT-2000 system and the physical layer design of SK Telecom system. Noticeably, the two-pilot scheme for inter-cell asynchronous mode and the timing control algorithm for the synchronization among the reverse channels are adopted.

Two search steps, cluster pilot search and cell pilot search can overcome the acquisition time bottleneck when the inter-cell asynchronous mode is used in the system. The simulation results of the two pilot scheme shows that about 90% mobile stations in the cell can acquire the pilot channel transmitted by the base station that they belong to in less than 200 msec.

The performance of the synchronous transmission in the reverse link is evaluated in comparison with the asynchronous transmission. The variation of the main path's arrival time in the reverse link is considered by changing the delay variables of the received signals in a random manner. In the proposed algorithm, MAI is reduced about 3 dB less than the asynchronous transmission irrespective of the number of MS's in case the ratio of the timing control rate to the channel variation rate is properly set. In addition, when the channel environment changes more abruptly, the performance degradation of the synchronous transmission can be compensated for by increasing the timing control rate.

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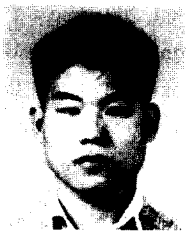

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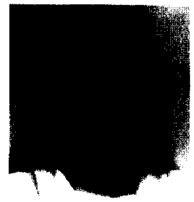

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