CDMA Mobile System Testbed and Field Test

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CONTENTS

ABSTRACT

This paper briefly explains the configuration of CDMA Mobile System (CMS) test bed. The measured fading and delay results of CDMA signal in Taejon area are shown. In comparison to other cellular systems, there are more parameters in the CDMA systems that affect system performance and capacity. We performed the optimization test of the selected parameters and present the effect of each parameter on the performance. This paper presents the capacity and performance test results of CMS. The capacity test was performed on ETRI site of three sectors in Taejon area. The performance tests include call completion rate, busy hour call attempt, and the delay characteristics of voice.

I. INTRODUCTION

This paper deals with the following four subjects: the CDMA signal propagation characteristics, the system parameter optimization for the power control and link budget under various mobile environments, the capacity and performance test results of the CDMA Mobile System (CMS), and the CMS system design issues.

The configuration and measurement system for the CMS testbed which has been designed and implemented to verify and evaluate the functionality and the performance of the CMS is described in section II. The RF signal propagation tests have been performed in the 800 MHz band which CMS uses. The fading and delay characteristics have been measured and analyzed. These results also are discussed in section II.

The CDMA system requires the power control to maximize the channel capacity by reducing the received E_b/N_o required for 1 % frame error rate (FER) of traffic channel. The power control involves many CDMA specific parameters. We need to analyze the effects of the CDMA parameters on the system performance, communication quality and the capacity. Section III discusses the experimental results for the parameter optimization.

Since the RF channel is shared by users in the CMS, the channel capacity per base station is a function of the desired communication quality. The higher the communication quality, the less is the capacity. It is also a function of the distribution and the speed of mobile users. Therefore, the CMS channel capacity must be verified through the field test. The field test has been performed by the CMS testbed which is deployed in Taejon area and section IV discusses the test condition and results.

Finally, unique features of the CMS that can be best utilized in the design of a mobile cellular system are discussed in section V.

II. CMS TESTBED AND TEST ENVIRONMENTS

1. Testbed Configuration

ETRI built the CMS testbed which is a comprehensively instrumented field test laboratory to achieve the following objectives :

1) To facilitate the integration of the subsystems and to develop the CDMA functions and the general features of cellular system during the first phase;
2) To evaluate the system capacity and performance during the second phase;
3) To optimize the CDMA radio link parameters during the third and current phase.

The testbed includes the minimum network that consists of home location center (HC), mobile exchange (MX), two base station control groups (BSCGs), three base station transceiver subsystem (BTSs) of

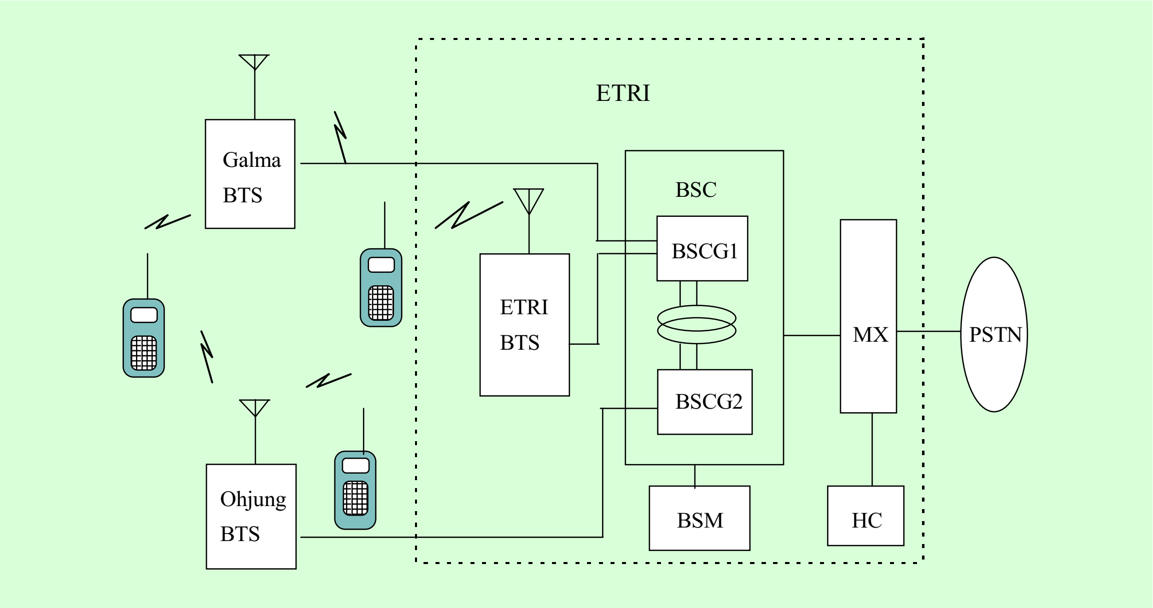

Fig. 1. The CMS network configuration.

five sectors in the Taejon area (see Fig. 1). The minimum network configuration makes it possible to test such features as the soft handoff among two or three cells, softer handoff between sectors, and soft and hard handoff between BSCGs.

The HC, MX, two BSCGs, and one BTS of three sectors were installed at the laboratory of system test plant (STP) in ETRI building #6. The two omnidirectional BTSs are located at Ohjung and Galma as shown in Fig. 2. The BTSs were positioned under the following guidelines. First, three ways soft handoff must be happened. Second, the environments of each BTS include a rural area, a residential area, and a commercial area. Third, one BTS consists of three sectors to help evaluate the maximum capacity per BTS.

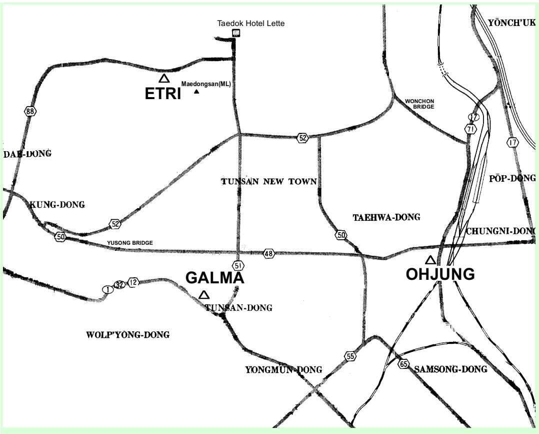

Fig. 2. The network topology of CMS testbed.

The three sectored BTS located at ETRI can be considered geographically a rural area. The two omnidirectional BTSs located at Ohjung-Dong and Galma-Dong can be considered a commercial region and a residential area, respectively.

2. Measurement Systems

The measurement systems consist of test van, measurement system of BS, field strength measurement system, and delay measurement system. The first two systems are used for measuring the performance of CMS. The remaining two systems measure the CDMA propagation characteristics.

Test Van

ETRI designed a test van to gather and record the received data during the capacity and performance test of the BTS. The test van consists of six MSs, two mobile diagnostic monitors (MDM), and a GPS receiver (see Fig. 3). The MDM has the functions of gathering the CDMA information from MS. It also records the mobile location and speed using GPS with dead recognition functionality.

Measurements System of Base Stations

During the capacity test and the optimization process, the test data are stored in analysis data logger (ADL) which is installed at BSC. CDMA system analysis tool (CSAT), that was developed by ETRI, is used as a dedicated analysis tool to post-process the stored data from MDM and ADL [1].

Field Strength & Delay Measurements System

Field strength measurement system was implemented to measure the path loss and fading characteristics. We use the current AMPS BTS as transmitter.

(a) Outside view.

(b) Inside view.

Fig. 3. The configuration of test van.

The delay measurement system has been developed. It is based on swept time delay cross-correlation (STDCC) sounding that uses the correlation property of pseudo-random sequence [2], which is m-sequence with 1024 length. The measuring resolution for time delay is 0.2 μs.

3. Propagation Characteristics

We measured and analyzed the signal strength and delay characteristics around Galma and ETRI BTSs. The results of the measurement are as follows.

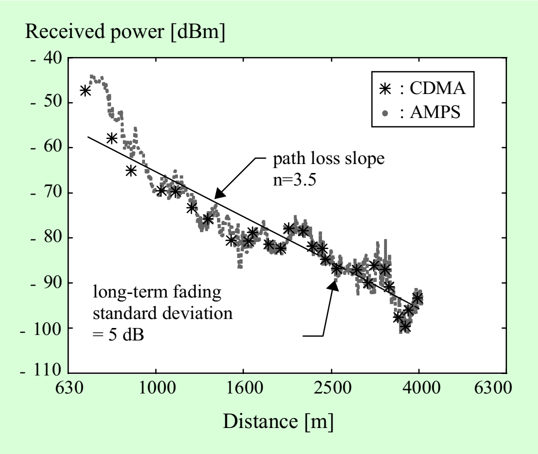

Fig. 4. Typical long-term fading around test stations.

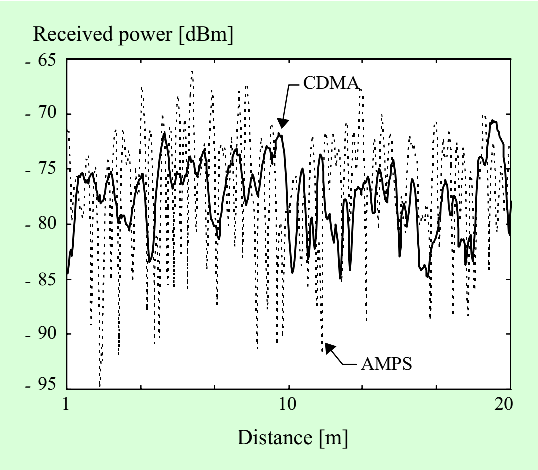

Fig. 5. Typical short-term fading characteristics measured in Taejon area.

Path Loss and Long-Term Fading [3], [4]

We measured the field strength of CDMA and AMPS system. Figure 4 shows the typical measured path loss and long-term fading around the test station. CDMA and AMPS signals had the similar characteristics of the path loss and the long-term fading. As a whole, the path loss slopes in the measured areas were 3-4 inverse power law. The standard deviation of long term fading having log-normal distribution was about 5 dB.

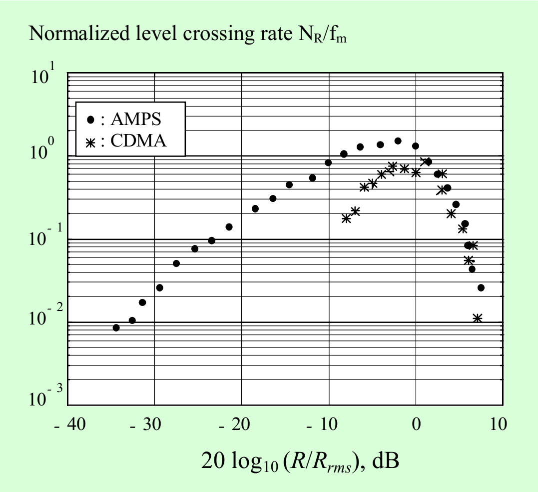

Fig. 6. Normalized level crossing rate for CDMA and AMPS signals (N_R: level crossing rate, f_m: maximum doppler frequency, R_{rms}: rms value of measured signals, R: measured signal envelope).

Short-Term Fading [3], [4]

Figure 5 shows the typical short-term fading characteristics in the same area. We can find the range of fading variations of CDMA signal is much smaller than that of AMPS signal. This results from frequency diversity effect of the wide band CDMA system. In order to obtain the quantitative characteristics of short term fading for CDMA and AMPS signals, we analyze the level crossing rate. The level crossing rate is defined as the expected rate at which the envelope crosses a specified signal level in the positive direction. Fig. 6 shows the normalized level crossing rates of CDMA and

AMPS. The range of signal variation for CDMA signal shows about 16 dB and that for AMPS signal is about 40 dB at normalized level crossing rate 10^{-2}.

Signal Delay Spread [2], [3], [5], [7]

The measurements were taken in the surroundings of two sites. Transmitter is located at each base station site and the height of transmitting antenna (H_{TX}) is 13, 24 meters and the height of receiving antenna is 2.1 meters above the ground level. Five routes were chosen within 3 km radius per site. The test sites are as follows : site A is ETRI BTS and site B is Galma BTS. We gathered 500 delay profiles from each course. The measuring interval for measuring each delay profile is about 1.2 second (10 meters). Among these profiles of each course, 250 profiles were chosen which showed the value of signal to noise ratio (SNR) over 10 dB, according to the rules suggested by Rappaport [6]. Threshold level is below 25 dB from the level of the dominant peak signal.

Delay spread characteristics for two sites are given in Table 1. The delay spread is standard deviation of each delay profile, and the average of the delay spread is the average of delay spreads of all profiles. Figure 7 shows the cumulative distribution functions (CDF) of delay spread for each site. The delay spread for two sites were less than 3.9 μs with probability of 90 %.

Table 1. Delay parameters in test areas.

Site	Average of rms delay spread
ETRI (H_{TX} = 24 meters)	2.08 μs
GALMA (H_{TX} = 13 meters)	2.45 μs

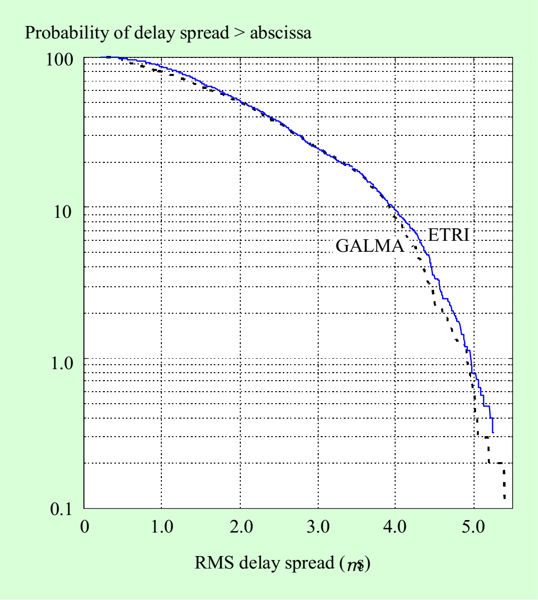

Fig. 7. Cumulative distributions of rms delay spread.

III. CDMA PARAMETER OPTIMIZATION

The performance and capacity of CMS are limited by the interference. Therefore, CMS adopts the power control algorithm to minimize interference, to maximize the capacity, and to maintain the required voice quality. In CMS, there are many parameters for power control to suppress the interference and for link budget. It is neces-

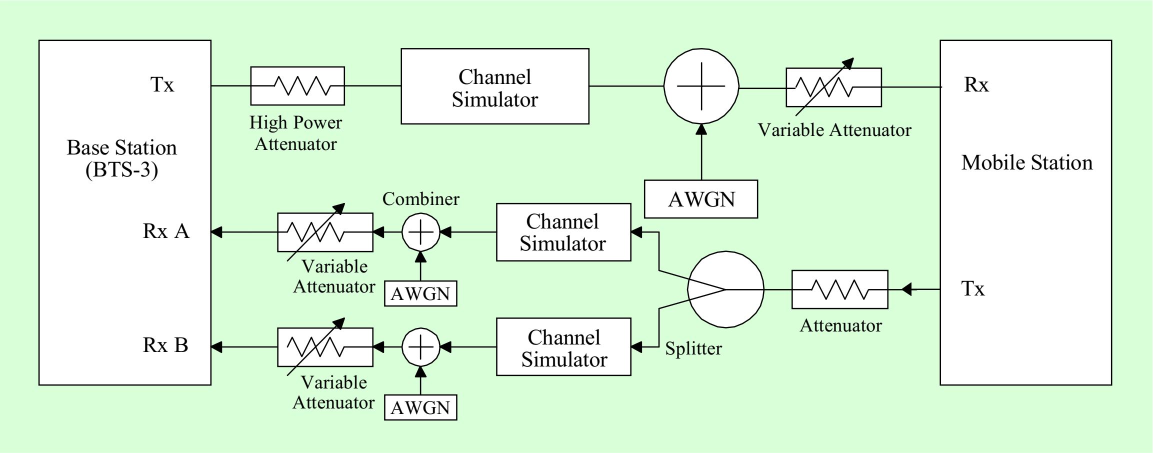

Fig. 8. Test configuration for link balance.

sary to analyze each parameter's sensitivity against the fading and delay as a function of the mobile speed and the radio environment. We have obtained the optimum parameter values in the test.

Table 2. The operating condition of mobile radio channel simulator.

	Case 1	Case 2
Frequency Number	466	466
Speed	30 km/h	100 km/h
Number of Paths	1	3
Path 2 Power (Relative to Path 1)	0 dB	0 dB
Path 3 Power (Relative to Path 1)	N/A	−3 dB
Delay from path 1 to input	0 sec	0 sec
Delay from path 2 to input	N/A	0.002 ms
Delay from path 3 to input	N/A	0.0145 ms

1. Test Conditions and Environments

In order to obtain the reproducible results, we chose the mobile radio channel simulator instead of the real field. We chose the following Rayleigh fading channel, which is shown in Table 2. They are recommended in IS-97 [11] and IS-98 [10].

In the optimization process, we chose the confidence interval, 5 minutes, in order to guarantee the test data and maintain FER below 1 % with 95 % confidence. We measured the data (forward/reverse FER, allocated forward traffic gain, cell received E_b/N_o, and E_b/N_o setpoint, etc.) 20 times using MDM and ADL and analyzed them statistically to produce the final results.

2. Link Balance between Forward and Reverse Links

The link balance between forward and reverse links is to make the same coverage under uniform loading condition and mobile radio environment [8]. The test configuration is shown in Fig. 8. The forward coverage is determined by the allocated power of pilot channel and the reverse one by the average E_b/N_o setpoint. Therefore, we increase or decrease the pilot gain and the maximum E_b/N_o setpoint (Pmax) by 1 dB step size. The pilot gain is 120, 108 (nominal), and 96. The Pmax is 10.5 dB (nominal), 9 dB, 8 dB, and 7 dB. During the test, the other parameters except them are set as the nominal values as shown in Appendix. We configured the channel simulator as both cases on Table 2. We assumed the number of active users as 30. The path loss between MS and BTS is 134 dB. The basic criterion is not only to maintain FER of all rate below 1 % but also to keep the mobile station received pilot E_c/I_o above −12 dB.

Table 3. The experimental results of link balance.

(a) Average FER comparison

Pmax Pilot	10.5 dB		9 dB	
	FWD	RVS	FWD	RVS
120	N/A	N/A	0.82 %	0.81 %
108	0.72 %	0.08 %	0.84 %	0.82 %
96	N/A	N/A	0.83 %	0.81 %

Pmax Pilot	8 dB		7 dB	
	FWD	RVS	FWD	RVS
120	0.85 %	0.88 %	0.83 %	2.69 %
108	0.78 %	0.9 %	0.88 %	2.52 %
96	0.9 %	0.9 %	0.85 %	2.79 %

(b) The compaison of average allocated forward traffic gain

Pmax Pilot	10.5 dB	9 dB	8 dB	7 dB
120	N/A	54.51	53.93	51.64
108	47.02	53.00	52.34	52.22
96	N/A	52.11	51.05	51.54

(c) The comparison of average mobile received E_c/I_o

Pmax Pilot	10.5 dB	9 dB	8 dB	7 dB
120	N/A	−8.20	−8.20	−8.12
108	−7.00	−8.82	−8.86	−8.87
96	N/A	−9.68	−9.69	−9.68

(d) The comparison of average cell E_b/N_o setpoint

Pmax Pilot	10.5 dB	9 dB	8 dB	7 dB
120	N/A	7.65	7.50	6.86
108	5.05	7.63	7.48	6.86
96	N/A	7.67	7.53	6.88

The optimization test results are shown in Table 3. First, we found that the variation of pilot power does not affect the FER and E_b/N_o setpoint of reverse link and the change of Pmax also do not affect the FER and traffic gain of forward link. Table 3(a) demonstrates that the forward FER is almost same regardless of the variation of pilot gain and the reverse FER is nearly same except Pmax 7 dB. The minimum traffic gain over the variation of pilot gain is obtained when the pilot gain is 96. These gain results in the minimum mobile received E_c/I_o, about −9.7 dB (see Table 3(c)). The reverse FER is abruptly changed from 0.08 % for Pmax 10.5 dB to about 0.88 % for Pmax 9 dB and 8 dB. It is due to the shortage of the maximum accessible

E_b/N_o setpoint. Table 3(d) tells that Pmax 8 dB results in minimum average cell E_b/N_o setpoint, about 7.5 dB, with 0.9 % FER. Therefore, the pilot gain 96 and cell E_b/N_o setpoint 8 dB is chosen as optimum value.

3. Power Control

Power control is the scheme of maintaining the received signal strength of each link at the minimum required value for communication. The perfect power control can solve the near far problem on the reverse link and reduce the interference between cells on both links. But there are some restrictions on power control such as the unreciprocity between forward and reverse links, the prediction error for channel condition, power control delay time, etc. in the actual environment. They decrease the radio capacity and worsen the traffic quality.

As the first step of the optimization test for power control, we select the mobile radio condition as Rayleigh fading channel and a number of power control parameters. The criterion of voice quality, FER, is below 1 % on this test. When we performed the optimization test for one parameter, we set the other parameter as the nominal value. After finishing the optimization test for selected parameter, we chose the best one among each results and did the performance test for the selected values.

A. Forward Link Power Control

The forward link power control is initiated by reporting the quality of forward link traffic channel, PMRM (power measurement report message), by MS to BTS [9]. The forward power control parameters in Appendix are the detail ones to change the transmit power of the traffic channel. At first, we have the intention to decrease the allocated gain of traffic channel, maintaining FER below 1 % and to adapt rapidly to the variation of mobile radio channel. We select the following parameters among them, as shown in Table 5. The algorithm of forward power control is to decrease the forward traffic gain continuously from the current value every fixed time interval (Slow_Down_Time, Fast_Down_Time) by the fixed step (Slow_Down_Delta, Fast_Down_Delta) when the reported FER in PMRM is below FER_Thres. As

Table 4. The optimum value for a given condition.

Pilot Gain	E_b/N_o Setpoint	Forward FER	Forward Tr. Gain	Mobile Rx. E_c/I_o	Reverse FER
96	8 dB	0.9 %	51.05	−9.69 dB	0.9 %

Table 5. The selected forward power control parameter and its range.

Parameters	Value	Remark
Step_Til_Fast	0, 1	
Slow_Down_Time	1,600∼4,200	ms
Fast_Down_Time	800∼1,600	ms
Fast_Down_Delta	1∼2	gain units
FER_Thres	3∼9	%

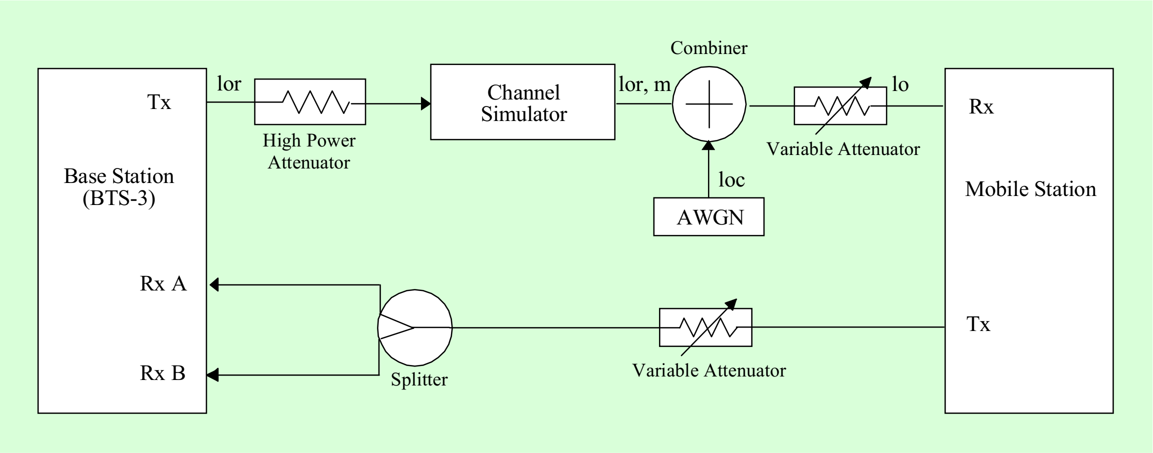

Fig. 9. Test configuration for forward link power control.

the reported FER in PMRM is above FER_Thres, BSC increases the current gain by Big_Up_Delta. As the reported FER is below FER_Thres and not zero, BSC increases the current gain by Small_Up_Delta. There are two ways to down the forward traffic gain. One is the fast mode and the other the slow mode. It is enabled by Step_Til_Fast.

The test configuration shown in Fig. 9 is the same one as the demodulation performance of forward traffic channel in multipath fading channel in IS-98 [10]. We selected the following two cases (see Table 6) among many demodulation tests in IS-98.

Table 6. The setting value for the test parameter.

	Case 1	Case 2
$I_{or,\ m}/I_{oc}$	4 dB	2 dB
E_c/I_{or} for Pilot channel	-7 dB	-7 dB
E_c/I_{or} for Traffic Channel (9,600 bps)	-9.5 dB	-14.7 dB
I_{oc}	-79 dBm/ 1.23 MHz	-77 dBm/ 1.23 MHz
Data Rate	9,600 bps	Variable
E_b/N_t for Traffic channel	15.6 dB	5.3 dB
Channel Model	Case 1	Case 2

The optimization test result for each parameter is shown in Table 7, respectively. The change of Fast_Down_Delta from one to two causes the lowering of the traffic gain with a little higher FER. But it is still below 1 %. The extending of Slow_Down_Time from 1,600 ms enhanced the measured FER. The shortening of Fast_Down_Time causes the decreases of forward traffic gain and the worsening of FER a little. The lowering of FER_Thres below nominal value induces the better FER with the increased traffic gain. The increases of FER_Thres from nominal value cause the same FER with the smaller traffic gain. In the view point of FER, there is no difference against

Table 7. The optimization test results for the selected parameter.

(a) The results for Step_Til_Fast(1) and Fast_Down_Delta

Channel	Case 1		Case 2		Remark
Fast_Down_Delta	FER (Full)	FWD Gain	FER(All)	FWD Gain	
1	0.72 %	47.02	0.8 %	51.06	Nominal
2	0.81 %	45.48	1.04 %	50.6	

(b) The test results for Slow_Down_Delta

Channel	Case 1		Case 2		Remark
Slow_Down_Delta	FER (Full)	FWD Gain	FER(All)	FWD Gain	
1,600	0.72 %	47.02	0.8 %	51.06	Nominal
2,900	0.63 %	48.94	0.69 %	50.78	
3,550	0.62 %	49.16	0.67 %	51.64	
4,200	0.58 %	52.15	0.67 %	52.59	

(c) The test results for Fast_Down_Time

Channel	Case 1		Case 2		Remark
Fast_Down_Time	FER (Full)	FWD Gain	FER(All)	FWD Gain	
800	0.88 %	45.92	0.97 %	47.71	
1,200	0.82 %	48.35	0.92 %	48.31	
1,600	0.72 %	47.02	0.8 %	51.06	Nominal

(d) The test results for FER_Thres

Channel	Case 1		Case 2		Remark
FER_Thres	FER (Full)	FWD Gain	FER(All)	FWD Gain	
3	0.56 %	51.23	0.67 %	54.7	
4	0.61 %	48.91	0.65 %	52.1	
6	0.72 %	47.02	0.8 %	51.06	Nominal
9	0.73 %	44.8	0.86 %	51.3	

the channel model. Other-wise, we found that the measured traffic gain of case 1 is lower than that of case 2. It is not due to the channel model but due to 2 dB higher I_{oc} and 2 dB lower $I_{or,m}/I_{oc}$.

The optimized value that is to lower the traffic gain with acceptable FER is shown in Table 8. The performance result of the optimized values is shown in Table 9. The forward FER is slightly decreased from 0.72 % to 0.69 % with the small increases of forward traffic gain under the channel model case 1. Otherwise, for channel model case 2 there is a decreases of FER from 0.8 % to 0.75 % with the decreased forward traffic gain. Both results satisfy our intention to decrease the allocated gain of traffic channel with maintaining FER below 1 %.

Table 8. Optimized forward power control parameter on a given Rayleigh channel.

Parameters	Optimized Value	Nominal Value	Remark
Step_Til_Fast	1	0	
Slow_Down_Time	3,550	1,600	ms
Fast_Down_Time	1,200	1,600	ms
Fast_Down_Delta	2	1	gain units
FER_Thres	4	6	%

Table 9. The performance comparison before/after optimization process.

Channel	Case 1		Case 2	
	FER (Full)	FWD Gain	FER (All)	FWD Gain
Before	0.72 %	47.02	0.8 %	51.06
After	0.69 %	48.02	0.75 %	48.08

Table 10. The selected reverse power control parameter and its range.

Parameters	Value	Remark
PD	12~96	
PVD	2~8	
Delta_Gain1	64, 96, 112	Forward P.C.

B. Reverse Link Power Control

There are three kinds of loops for the reverse link power control in CMS, which are open loop, closed loop and outer loop, and the relating parameters are listed in the Appendix.

Table 11. The setting value for the test parameter.

	Case 1
AWGN Power at BTS	-84 dBm/1.23 MHz ± 5 dB
Channel Model	Case 2

At first, we select the following parameters among them, as shown in Table 10. PD and PVD are the down step size of the E_b/N_o setpoint when BSC receives good frame of full rate and 1/8th rate. The guideline of selecting them is to lower the received E_b/N_o and the threshold of BTS, maintaining FER below 1 %. The reason for selecting the Delta_Gain1 is that we have MS receive the power up and down command of 800 bps from BTS more correctly. The test configuration is shown in Fig. 10 and is the same one as the demodulation performance of forward traffic channel in multipath fading channel in IS-97 [11]. We selected the following one case (see Table 11) among many demodulation tests in IS-98 due to the impossibility to setup E_b/N_o boundary (recommended value by IS-97) in CMS.

The optimization test result for PD, PVD, and Delta_Gain1 is shown in Table 12, respectively. The influence of PD on FER is the biggest among them. If PD is increased from nominal, FER becomes larger

Table 12. The optimization test results for the selected parameter.

(a) The results for PD(Power down step for good frame of full rate)

PD	FER			E_b/N_o	Rx.	Remark
	All rate	Full Rate	1/8 rate	Setpoint	E_b/N_o	
12	1.1 %	1.28 %	1 %	7.04 dB	7.84 dB	
18	0.6 %	0.6 %	0.63 %	7.44 dB	8.23 dB	
24	0.75 %	0.76 %	0.74 %	7.26 dB	8.15 dB	Nominal
42	1.01 %	1.15 %	0.92 %	7.13 dB	7.89 dB	
96	1.74 %	2.39 %	1.35 %	6.74 dB	7.51 dB	

(b) The test results for PVD(Power down step for good frame of 1/8 rate)

PVD	FER			E_b/N_o	Rx.	Remark
	All rate	Full Rate	1/8 rate	Setpoint	E_b/N_o	
2	0.7 %	0.7 %	0.7 %	7.4 dB	8.22 dB	
4	0.75 %	0.76 %	0.74 %	7.26 dB	8.15 dB	Nominal
8	0.84 %	0.9 %	0.79 %	7.26 dB	8.03 dB	

(c) The test results for Delta_Gain1

Delta Gain1	FER			E_b/N_o	Rx.	Remark
	All rate	Full Rate	1/8 rate	Setpoint	E_b/N_o	
64	0.75 %	0.76 %	0.74 %	7.26 dB	8.15 dB	
96	0.74 %	0.75 %	0.74 %	7.3 dB	8.13 dB	Nominal
112	0.74 %	0.75 %	0.74 %	7.31 dB	8.11 dB	

while E_b/N_o becomes smaller. This is because outer loop decrease E_b/N_o setpoint bigger step-size every time BSC receive the consecutive good frames of full rate. Otherwise, The PVD effect on FER and E_b/N_o is not noticeable due to the small step size over the consecutive good frames of 1/8th rate. The lowering of PVD makes the lower FER and the higher E_b/N_o. But if PD digresses from nominal 24, the FER is increased and E_b/N_o becomes smaller. The change of Delta_Gain1 does not affect on FER and E_b/N_o due to no fading on forward link. Therefore, we need to reoptimize

Table 13. Optimized reverse power control parameter on a given Rayleigh channel.

Parameters	Optimized Value	Nominal Value	Remark
PD	18	24	
PVD	2	4	
Delta_Gain1	112	64	Forward P.C.

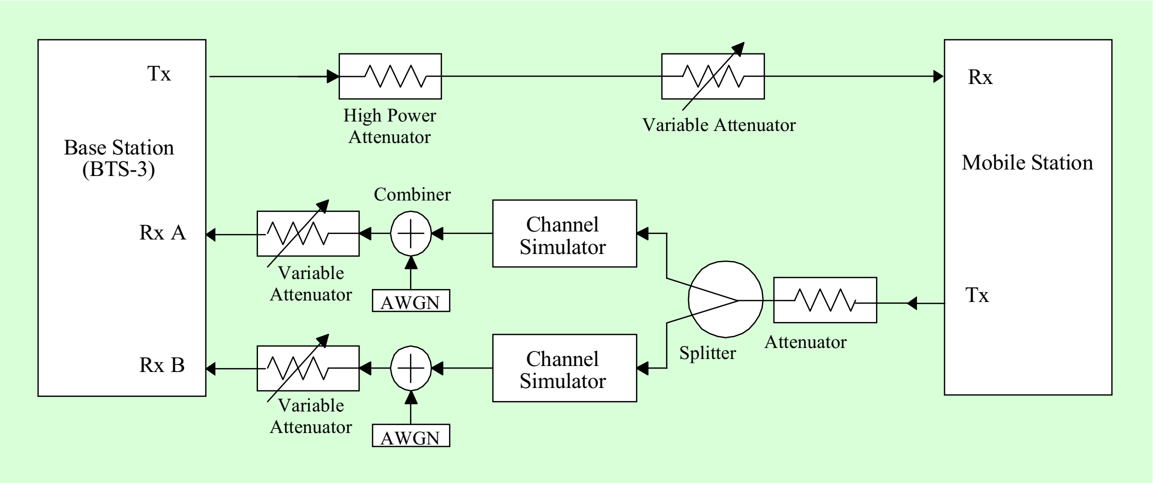

Fig. 10. Test configuration for reverse link power control.

Table 14. The performance comparison before/after optimization process.

	FER			E_b/N_o	Rx.
	All rate	Full Rate	1/8 rate	Setpoint	E_b/N_o
Before	0.75 %	0.76 %	0.74 %	7.26 dB	8.15 dB
After	0.53 %	0.51 %	0.55 %	7.65 dB	8.41 dB

Delta_Gain1 under the well-configured test condition.

The optimized value that is to lower E_b/N_o with acceptable FER is shown in Table 13. The performance result of the optimized parameter values is shown in Table 14. The FER of reverse link is decreased from 0.75 % to 0.53 % with the small increases of E_b/N_o Setpoint and Rx. E_b/N_o.

Throughout the whole results, we can easily found out that there was about 0.8 dB difference between E_b/N_o setpoint and Rx. E_b/N_o. As you know, we have two kinds of power control mechanism in CDMA system: One is open loop and the other is closed loop. It is due to the power control error which is mainly caused by power control delay. The power control delay comes from the inherent closed loop delay and the unequal weight of multipaths.

IV. CAPACITY AND PERFORMANCE TEST

1. Link Capacity

The capacity test of CDMA system was performed by Qualcomm,. in 1991. In the test, Qualcomm used a kind of test system not commercial equipment. Afterward, there was no capacity test of CDMA system by using the commercial equipment. We performed it by CMS which is actual commercial equipment of field test site in Taejon.

As mentioned in Section II. 1, CMS testbed has just three BTSs with five sectors. We have tested fully loaded link capacity. Therefore, we performed the capacity evaluation test of single cell with three sectors with real MSs. We do not insert the simulated users into system during the capacity test.

There are many factors which affect the capacity of CDMA system. They are MS speed, the distribution of MS, and, loading status of adjacent cells. Therefore, we made some kind of test scenarios in capacity test. First, we divide MS speed into stationary state and moving state. Second, we distributed MSs on the designated test routes which is decided on the basis of MS received power. We did two tests. One is the capacity test on isolated sector and the other is three sectors test. During the test, we installed four MSs per one car and divided two groups.

The capacity test per one isolated sector was performed on July of 1995. During the field test, we selected the two test routes according to the MS received power. The route 1 is the route at which the MS received power is higher than −65 dBm, and the route 2, lower than −65 dBm.

The test result was in Table 15 and the measured quality of traffic channel on both uplink and downlink was below 1 % FER. We found that the maximum achieved capacity is 45 MSs on route 1 with stationary case. This is 74 % of Qualcomm test. Qualcomm got 61 simultaneous calls per one sector which is located in Fiesta Island of San Diego [13]. The lowered capacity is primarily due to the different test environments. ETRI site is almost rural area and MSs is densely crowded in the limited area while Fiesta Island is open area and MSs is uniformly distributed. The capacity on route 2 is 75 % of that of on route 1 for stationary case. For the moving case the capacity is 78 % of the stationary case of route 1 and 59 % of that of route 2. We found that the larger power the MS received and the slower speed the MS was, the larger the capacity became. The average capacity was measured in the case that MSs were distributed uniformly in service area. Finally, Table 15 demonstrates that the capacity of CMS BTS was determined by the distribution and the speed of MSs, and the characteristics of mobile environments.

Table 15. Maximum capacity on a sector.

Route	Stationary	Moving (< 60 km/h)	Miscellaneous
1	45	35	
2	34	20	
1,2	39	27	MSs evenly distributed at route 1, 2

The three sector capacity test was performed on December of 1995. During the field test, the MS received power on each route is greater than −70 dBm. The test result in Table 16 shows that the capacity for moving case is 79 % of the stationary case. It is almost the same as the capacity test on a sector.

Table 16. Maximum capacity on BTS with 3 sectors.

Stationary	Moving (< 30 km/h)	Miscellaneous
68	54	MSs evenly distributed at each sector

The Service Option 2 [14] with Loop Back mode developed in CMS was used in the test. We set CDMA parameter as the optimized values for the test. To evaluate the quality of each traffic channel, MS, BTS and BSC gather the necessary data using MDM and ADL, respectively. The recorded data was analyzed by using CSAT.

2. Delay Performance in Traffic Channel

The digital cellular system must send and receive the digital voice data on the air channel. It adds the extra processing delay of analog-to-digital and digital-to-analog transformation to the propagation delay. The analog voice is converted to the digital voice by the MS vocoder and transmitted to BTS, and it is converted again to the PCM signal of 64 Kbps at the TSB in BSC. If the delay is long enough to cause echo on the transmitted voice, we need echo canceller in our system. It is necessary to measure the delay accurately to compensate it by echo canceller.

The delay characteristic was measured on the traffic channel of mobile-to-land path, land-to-mobile path, and mobile-to-mobile path. We use a Visicoder with 1 kHz audio tone as a test equipment for the delay measurement.

The delay for mobile-to-mobile path is about 180 ms, for mobile-to-land 100 ms, and for land-to-mobile about 120 ms. Fig. 11 shows the sample graph of the measured voice delay for mobile-to-land path.

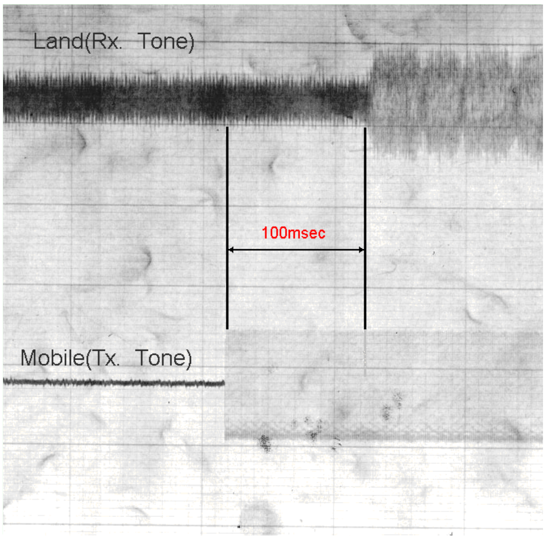

Fig. 11. The delay performance of voice for mobile-to-land path in CMS.

3. Call Completion

Call completion rate is to test whether a system successfully connects the continuous call attempts from many mobile stations to each designated parts or not and what the success rate is. This index indicates the system performance of call completion under the normal condition of system. The maximum call completion rate per BTS was evaluated in this paper.

The formal call completion test must be required to allocate properly the ratio of mobile-to-land call, land-to-mobile call, and mobile-to-mobile call. However, we do not have an automatical and continuous call generating system between MS and land at present. We measure the call completion rate by using mobile call simulator (MCS) that can automatically generate mobile-to-mobile call at the predefined condition. The sixteen MSs and two sets of MCS were used in the test, each MCS had eight MSs, and there is a mobile-to-mobile call among the same MCS. During the test, the total talk time is 90 sec, the idle time 10 sec. The test time was one hour.

The measured call completion rate was 90 %. The setup failure is 6 % and the call drop during the call is 4 %. The setup failure is slightly higher. Then, we need to ameliorate the call processing performance.

4. Busy Hour Call Attempts

Usually, we do busy hour call attempts (BHCA) test to system to find out and verify whether the system's call processing function is working properly after we apply to the system high loading, that is, heavy call attempts per an hour. This test verify the system resistance to heavy load test. Therefore, we do not usually care about the call completion rate in this test. The BHCA per BTS was also evaluated in this paper.

This test also must be performed under the appropriate allocation of registration and the three kinds of call. However, It was measured by only mobile-to-mobile call due to using MCS. We used 32 MSs and two sets of MCS. The average talk time and the idle time were 7 s and 5 s, respectively. The test duration was 10 minutes.

The measured BHCA was 3,100 calls per hour. When we finished this test, we placed a normal mobile-to-land, land-to-mobile, and mobile-to-mobile calls to verify the functionality of call processing of CMS. There is too much setup failure at the originating MS and no page response at the terminating MS during the test. These extend the call time per one call approximately two or more times. The way to evaluate the BHCA performance more accurately is to extend the total call time per one call and to combine the rate of registration and three kinds of call appropriately.

V. CMS FEATURES AND DESIGN CONSIDERATION

The propagation measurement result of CDMA signal is reflected in the design of CMS system. The measured number of multipath is used to decide the number of demodulator at MS and BTS. The measured delay profile determines the maximum searching window size of demodulator and of searcher for the acquisition and tracking of the pilot. The fading characteristic over distance is used for power control, especially open loop. As we found that the speed of closed power control, 800 bps, is low to combat with the fast fading because the measured fading duration is too short, we adopt and implement interleaver. The size of interleaver is 16×24 matrix to randomize the burst error.

The fact that the capacity and performance tests were successful in Taejon area under the optimized parameter expedites the developed CMS for the stable commercial service. The results through the optimization process and link balance are useful to the design of CDMA mobile network, that is, cell planning.

We have the following topics to do in the future for more stable and successful service of commercial CMS.

1. In this paper, we took parameter optimization under two kinds of mobile radio channels. More parameter optimization processes under various mobile radio environments are needed. Therefore, we classify the representative channel condition of rural, urban, suburban, downtown and highway. We need to find out the parameter sensitivity to each mobile radio condition. The optimized parameter through the various radio channels is applicable to the deployed commercial CMS.
2. As we are on the transient period from AMPS to CDMA, both systems are to coexist. Therefore, MS that is nearby other systems experiences the intermodulation interference and degrades FER. We must accurately analye the CDMA-to-AMPS interference and search for the way to minimize it.
3. As the cellular system is divided into the two operating companies, we must experience the interference between the operating companies due to the different location of BTS. We proceed the more quantitative test to find the way to reduce it.
4. The performance simulation of wideband CDMA PCS will be possible with the basis of these tests.

VI. CONCLUSION

The propagation characteristics of CDMA signal, path loss and delay, were presented in this paper. The path loss slope characteristic of CDMA signal is similar to that of 30 kHz AMPS signal. The measured delay spread confirmed the rake receiver design of the CMS testbed.

We also performed the CDMA parameter optimization test. We select the parameters among the link balance and the forward and reverse power control to decrease FER on both links and decrease the allocated traffic gain on forward link and E_b/N_o on reverse link. The link balance test shows that it is needed to reduce the pilot gain and Pmax from current values under the mobile channels in test. In order to have better FER and less traffic gain on forward link, we need to enable the Step_Til_Fast mode, extend Slow_Down_Time, reduce Fast_Down_Time and FER_Thres from current values of forward ward power control. The parameter optimization test for reverse link power control shows that the decreases of PD and PVD from current values provide better FER with slightly increased E_b/N_o. The results that are obtained through the optimization processes will be applicable to deployment of the CMS in the near future.

The CMS testbed including the various measurement systems were setup to develop and evaluate the CMS function and performance. Through the field and laboratory tests, we have achieved that the CMS testbed has the good call completion rate, acceptable busy hour call attempt, and the compensatable voice delay. The measured maximum capacity per a sector is 45 users and that per a BTS with three sector is 68 users.

APPENDIX: CMS NOMINAL PARAMETER

- BTS parameter record

Field		Suggested	Definition
System Parameter	Pwr_Rep_Thresh	2	Number of forward frame errors an MS must detect before sending a PMRM message
	Pwr_Rep_Frames	7	The number of forward frames over which MS must count frame errors before sending a PMRM message
	Pwr_Thresh_Enable	1	Threshold report mode indicator
	Pwr_Period_Enable	1	Periodic report mode indicator
	Pwr_Rep_Delay	5	Period an MS must wait after sending an autonomous PMRM message before restarting frame counting for power control
Paging	Tx_Gain	65	Paging channel transmit gain
Pilot	Pilot_Gain	108	Pilot channel transmit gain
Sync	Sync_Gain	34	Sync channel transmit gain

- Forward power control record

Field	Suggested	Definition
Step_Til_Fast	0	Number of consecutive slow down power control steps before switching to fast down power control
Slow_Down_Time	1,600	Time (ms) between down steps for slow power control
Fast_Down_Time	1,600	Time (ms) between down steps for fast power control
Slow_Down_Delta	1	Magnitude of the slow down steps in gain unit
Fast_Down_Delta	1	Magnitude of the fast down steps in gain unit
Nom_Gain	50	Nominal Tx gain in gain unit
Max_Tx_Gain	80	maximum Tx gain in gain unit
Min_Tx_Gain	40	minimum Tx gain in gain unit
FER_Thres	6	FER (%) threshold determining fast or slow gain increase
Big_Up_Delta	10	Large gain increase in gain unit
Small_Up_Delta	5	Small gain increase in gain unit
Signal_Delta_Gain	96	Signaling traffic frame gain delta (gain in 64ths)
Delta_Gain1	64	Minimum 1 cell power control subchannel gain delta (gain in 64ths)
Delta_Gain2	96	Minimum 2 cell power control subchannel gain delta (gain in 64ths)
Delta_Gain3	112	Minimum 3 cell power control subchannel gain delta (gain in 64ths)

- Reverse outer loop power control record

Field	Suggested	Definition
FER Set Point	1 %	Target FER
Pnom	19416(7.5 dB)	Initial target E_b/N_o which is the starting point when the call is setup.
Pmax	61144(10.5 dB)	Maximum target E_b/N_o during the call

Field	Suggested	Definition
Pmin	8288(5.0 dB)	Minimum target E_b/N_o during the call
PUPF	3720	Up step size for erase in full mode
PUPE	248	Up step size for erase in erase Run
PUPEL	50	Up step size for erase run
PD	24	Down step size for full rate mode
PVD	4	Down step size for variable rate mode
PFW	1	Pause between up fulls
PFRR	−2	Minus fulls step size until full rate mode
PERL	5	Erasure step size until erase mode

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