Experiment and Simulation Results of Adaptive Antenna Array System at Base and Mobile Stations in Mobile Environment

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Abstract

In a time division duplex (TDD) based adaptive array antenna (AAA)/space division multiple access (SDMA) system, the array weights determined from up-link signals can be applied to the down-link transmission because of the channel reciprocity. However, under fast fading conditions, for example due to fast moving mobile station (MS), the array weights are no longer optimum for the down-link signal transmission and hence the spectral efficiency of the system degrades in down-link. In this paper, we present the computer simulation and field experiment down-link performance of MS with two antenna elements moving at various velocities in the field trial system of i-Burst, which is a wireless broadband system employing AAA and SDMA techniques. Both the results show that adaptive antenna processing at MS is effective in improving the mobility performance of TDD-AAA/SDMA system.

1. INTRODUCTION

To meet the ever increasing demand for mobile communication services, adaptive antenna array (AAA) and space division multiple access (SDMA) techniques have been increasingly employed due to their ability to increase the system capacity [1]-[6]. The AAA makes it possible to mitigate received power fading of desired signal due to its diversity effect and reduce spectrum re-use distance due to its ability to suppress co-channel interference (CCI) [7]. The SDMA spatially separates mobile stations (MSs) by different beam patterns generated at base station (BS). Thus, the same channel can be simultaneously used by multiple MSs.

In a time division duplex (TDD) based AAA/SDMA system, the array weights determined from up-link (MS to BS communication) signals can be applied to the down-link (BS to MS communication) signal transmission because of the channel reciprocity. However, under fast fading conditions, for example due to fast moving MS, the array weights are no longer optimum for the down-link signal transmission. Thus, the received power of the desired signal decreases. Moreover, if other MSs use the same channel, the desired signal is interfered by other MSs' signals. As a result, these cause degradation of spectral efficiency in down-link [8][9]. In order to improve mobility performance of TDD-AAA/SDMA system, we think that applying AAA to a MS is effective. This improvement effect depends on propagation environment, its variation degree, and antenna spacing.

Fig. 1: i-Burst BS.

In this paper, we introduce a prototype of MS with 2-element antenna array and present the computer simulation and experimental performance results of mobility in a field trial system of i-Burst system [10], which is a wireless broadband system employing AAA and SDMA techniques at BS. This paper is organized such that Section 2 introduces i-Burst system and explains the AAA and SDMA features of it. In Section 3, we introduce and explain the developed prototype of MS employing 2-element AAA. In Section 4, the results of computer simulations are presented. Finally, the results of field experiments are presented in Section 5.

TABLE 1: PARAMETERS OF I-BURST SYSTEM.

System	TDD-TDMA/SDMA
Carrier frequency	2005.3125 MHz
Symbol rate	500 ksps
Down-link modulation type	π/2-BPSK, QPSK, 8PSK, 12QAM, 16QAM, 24QAM
BS	
Pulse shaping filter on BS transmitter	Root-raised cosine filter with roll-off factor 0.25
Number of antenna elements	12
Antenna topology	Circle
Antenna spacing	3.5λ
Adaptive Antenna Processing Criterion	MMSE

TABLE 2: USER DATA THROUGHPUT AT VARIOUS MODCLASSES.

Mod Class	Down-link target SINR (dB)	Single stream down-link throughput (kbps)	Aggregated 3 stream down-link throughput (kbps)
0	-0.5	35.2	105.6
1	1.3	49.6	148.8
2	2.8	81.6	244.8
3	5.7	126.4	379.2
4	7.9	161.6	484.8
5	10.1	198.4	595.2
6	12.2	262.4	787.2
7	13.5	307.2	921.6
8	15.4	353.6	1060.8

2. TDD-AAA/SDMA STRUCTURE OF I-BURST [10]

The adaptive antenna system and the parameters of i-Burst system used for the field experiments are shown in Fig. 1 and Table 1, respectively. The i-Burst supports link adaptation which uses various modulation/coding scheme pairs called ModClass. Therefore, throughput is strongly influenced by the link condition. The target down-link signal to interference plus noise ratio (SINR) and the user data throughput (i. e., delivered end-user data rate after removing overhead) for each ModClass are shown in Table 2.

An i-Burst BS employs 12-element antenna array. For the field experiments, an antenna array with circular topology where adjacent antenna elements are spaced apart by 3.5λ is considered. The AAA/SDMA signal processing block diagram of the BS is shown in Fig. 2. For the up-link reception, the BS mitigates received power fading of desired signal by steering the beam to the focused MS. In addition, when the BS communicates with multiple MSs on the same channel, the BS picks up the desired signal by nulling interfering signals from other MSs. The array weights for these beam patterns can be generated by processing the received up-link training sequences by using minimum mean square error (MMSE) criterion. The i-Burst frame and slot structure are shown in Fig. 3. For the down-link transmission, the array weights determined for the up-link are applied, using the reciprocity of the TDD channel. Therefore, the desired signal is transmitted only to the desired MS and not to other MSs. The TDD-SDMA can be obtained by applying this operation to two or more MSs.

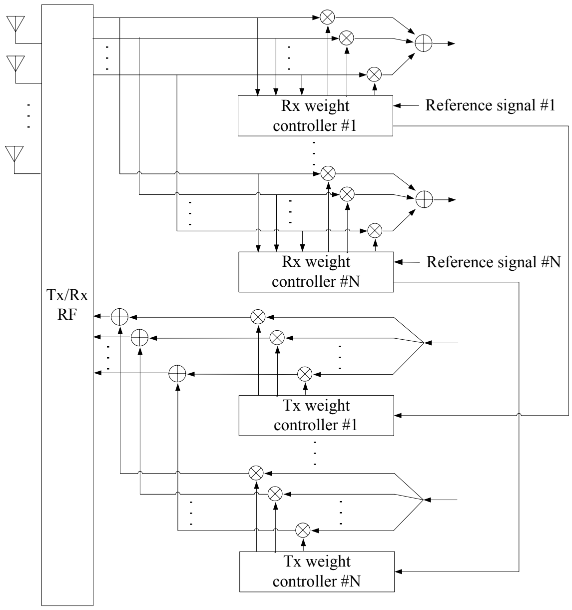

Fig. 2: AAA/SDMA Signal Processing Diagram of BS.

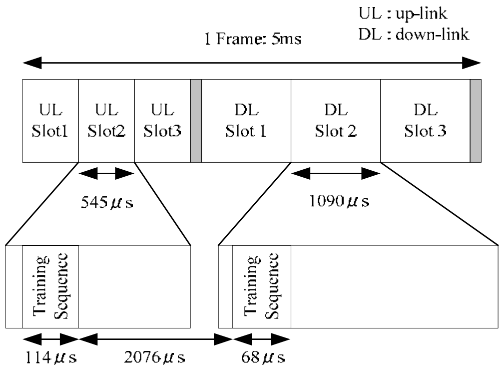

Fig. 3: The i-Burst Frame and Slot Structure.

3. I-BURST EVALUATION MS EMPLOYING AAA

The performance improvement in the SINR and throughput performance as a result of using 2-element AAA in the MS is evaluated in this paper.

A. Structure of Evaluation Device

The prototype board of MS with AAA signal processing unit and its block diagram are shown in Figs. 4 and 5, respectively. The parameters of this MS board under evaluation are shown in Table 3. It has two antenna elements: the transmitter uses only single element whereas the receiver uses both antenna elements. The digital intermediate frequency (IF) signals from i-Burst radio frequency (RF) modules are applied to the AAA signal processing unit. The IF-BB module converts the IF signals into the baseband (BB) signals which are used to calculate array weights. The processing of IF signals is delayed using first-in first-out (FIFO) memory. The FIFO

TABLE 3: PARAMETERS OF MS EVALUATION BOARD.

Number of antenna elements	2
Directivity of antenna element	Omni
Antenna spacing	0.5λ
Adaptive Antenna Processing Criterion	MMSE
Optimization algorithm	SMI
FIFO buffer size	8.52kbit

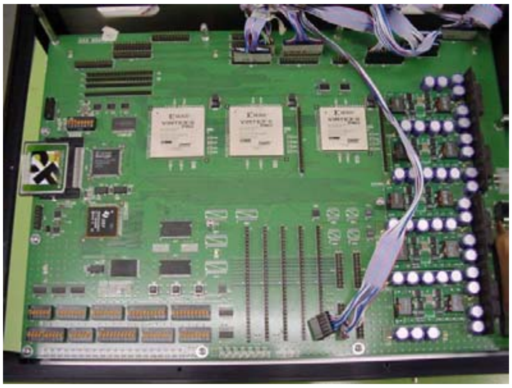

Fig. 4: Prototype Board of MS with AAA.

memory output signals are combined with the array weights and then processed with conventional i-Burst signal processing unit. For performance evaluation, the MS evaluation board is connected to a personal computer (PC) and the SINR values calculated by i-Burst signal processing unit are recorded on the PC. In addition, throughput in kilobits per second is calculated on the PC by measuring the ftp downloaded file size per second.

B. Array Weights Calculation

The weight controller calculates the array weights based on the MMSE criterion. MMSE is one of the popular and very effective criteria to mobile communication because the angle of arrival (AoA) information of the signals is not required. The optimum array weights for MMSE are determined by minimizing the mean square error between the reference signal and the array output signal. The down-link training sequence of 34 symbols is used as the reference signal. The weight controller uses sample matrix inversion (SMI) algorithm and the array weights $\boldsymbol{w}(m)$ are calculated as

$$R_{xx}(m) = \frac{1}{m}\sum_{i=1}^{m}\boldsymbol{x}(i)\boldsymbol{x}^{H}(i)\ . \tag{1}$$

$$\boldsymbol{r}_{xr}(m) = \frac{1}{m}\sum_{i=1}^{m}\boldsymbol{x}(i)r^{*}(i)\ . \tag{2}$$

$$\boldsymbol{w}(m) = R_{xx}^{-1}(m)\boldsymbol{r}_{xr}(m)\ . \tag{3}$$

where $\boldsymbol{x}(i)$ are the array received signals converted to the BB, $r(i)$ is the reference signal and m is the number of samples [11]. These array weights are applied to the received IF signals delayed by FIFO memory, as shown in Fig. 6. The weighted combined signal is then processed by the i-Burst signal processing unit.

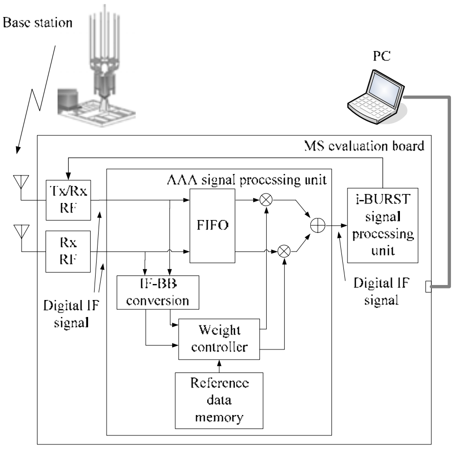

Fig. 5: Block Diagram of MS Evaluation Board.

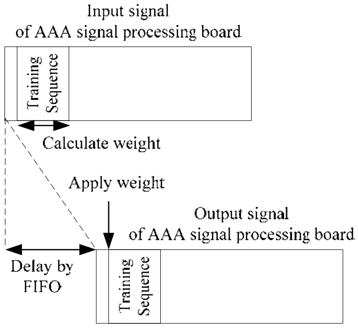

Fig. 6: Weight Applying Timing.

4. COMPUTER SIMULATIONS AND THE RESULTS

The spatial channel model and the parameters used for the simulations are shown in Fig. 7 and Table 4 [12]. We assume a suburban macrocell environment in order to compare with the experimental results. A 6-path channel is assumed for simulation. Each path has its own spatial parameters (power, AoA, delay time). We use vehicular A power delay profile for the paths [12]. Each path is a cluster of 8 independent sub-paths with the same delay time and the same power. The initial phase of each sub-path is independent and uniformly distributed from 0 to 360 degrees. The initial phases between up-link and down-link are fully correlated. Both the AAA and the equalizer are constrained by the first arrival path. The tap coefficients of the equalizer are calculated after the array weight calculation and the weighted combining. The SINR is calculated by using the received down-link training sequences as

$$SINR = \frac{\left|s'\right|^2}{\frac{1}{N_{TS}}\sum_{i=0}^{N_{TS}-1}\left|y(i)r^{*}(i) - s'\right|^2} \tag{4}$$

$$s' = \frac{1}{N_{TS}}\sum_{j=0}^{N_{TS}-1}y(j)r^{*}(j) \tag{5}$$

TABLE 4: PARAMETERS OF SIMULATION.

Power delay profile	Vehicular A
Number of paths	6
Number of sub-paths per path	8
BS	
Average SNR per antenna	20 dB
AoA offset of sub-paths per path	Laplacian distribution
Angle spread per path	RMS 2 degrees
AoA of paths	Gaussian distribution
Angle spread of paths	RMS 2.4 degrees
AoA difference per path between MSs	0 degrees
MS	
Equalizer	4 taps transversal equalizer with tap interval T/2
AoA of all sub-paths	360 degrees uniform distribution
Velocity	3, 20, 40 kmph

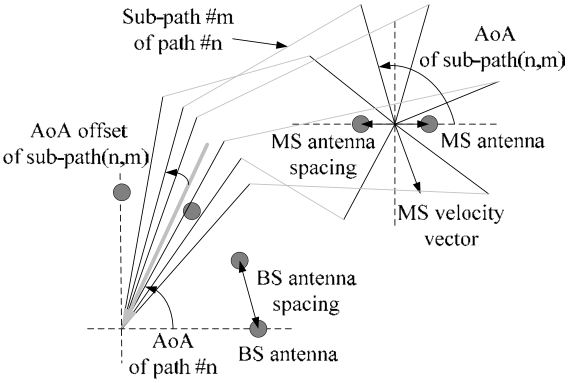

Fig. 7: Spatial Channel Model.

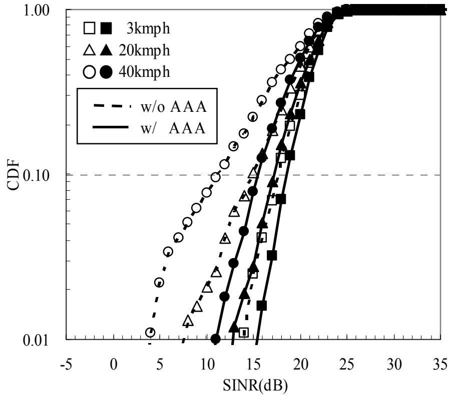

Fig. 8: CDF of SINR in Simulation of the AAA Mode.

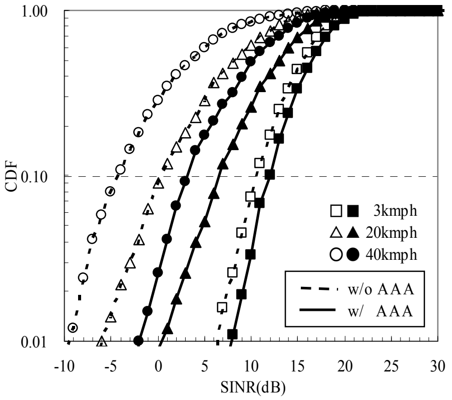

Fig. 9: CDF of SINR in Simulation of the SDMA Mode.

where $y(i)$ is the output of the equalizer for the received down-link training sequence, $r(i)$ is the transmitted down-link training sequence, and N_{TS} is the number of the down-link training sequence symbols. In the i-Burst system, the delay time of each time slot between the up-link training sequence and the down-link transmit time slot is different because of the asymmetric up-link and down-link slot size. In this paper, we evaluate the performance only for time slot #2 (Fig. 3). The number of MSs is 1 for AAA mode and 2 for SDMA mode. In the SDMA mode, the carrier to interference power ratio (CIR) is 0dB.

The cumulative distribution functions (CDFs) of SINR in the AAA mode and the SDMA mode are shown in Figs. 8 and 9, respectively. It can be observed from Figs. 8 and 9 that in the AAA mode without MS-AAA, there is a degradation of 6.1 dB in the SINR for 40 kmph from the SINR for 3 kmph at CDF of 0.1. With MS-AAA, the SINR is improved by 4.0 dB. On the other hand, in the SDMA mode without MS-AAA, there are degradations of 10.6 dB and 15.0 dB for 20 kmph and 40 kmph, respectively from the SINR for 3 kmph at CDF of 0.1. With MS-AAA, the SINRs are improved by 6.2 dB and 7.6 dB for 20 kmph and 40 kmph, respectively. Thus, the degradation of the down-link performance encountered with the fast moving MS is significant in the SDMA mode and the AAA applied to MS provides significant improvement of SINR due to the CCI suppression effect. Also, both the SINR degradation without MS-AAA and the SINR improvement with MS-AAA increase as the velocity becomes high.

5. FIELD EXPERIMENTS AND THE RESULTS

The field experiments were carried out for two cases- case 1: a constant velocity drive test to examine the performance at a given velocity of MS and case 2: a normal drive test to examine the performance for various velocities. These tests were carried out in the suburban and urban environments. In the SDMA mode, both the MS board for AAA evaluation (AAA-MS) and the spatially multiplexed MS (interfering MS) were placed two meters apart in the same car. To remove the performance difference between the MSs, we measured the performance of the AAA-MS by switching the AAA function on and off. A single cell is considered.

A.Results of Constant Velocity Drive Test

The measurement condition of the constant velocity drive test is shown in Table 5. Down-link power control of the i-Burst BS was stopped. In the SDMA mode, the CIR is 0dB. The CDFs of SINR in the AAA mode and the SDMA mode are

TABLE 5: THE MEASUREMENT CONDITION OF CONSTANT VELOCITY DRIVE TEST.

Area	Suburban
BS antenna height	30 m
MS antenna height	1 m
Difference of ground height between BS and MS	28 m
Distance between BS and MS	1.0 ~ 1.3 km
Velocity	~5, 20, 40 kmph

TABLE 6: COMPARISON BETWEEN SIMULATION AND EXPERIMENT AT CDF OF 0.1.

Test type		Simulation			Experiment		
Velocity (kmph)		3	20	40	~5	20	40
AAA mode	SINR degradation w/o AAA (dB)		2.7	6.1		1.4	5.4
	SINR improvement w/ AAA (dB)	1.0	2.3	4.0	-0.9	-1.0	1.8
SDMA mode	SINR degradation w/o AAA (dB)		10.6	15.0		7.3	12.0
	SINR improvement w/ AAA (dB)	1.3	6.2	7.6	0.7	4.1	4.5

shown in Figs. 10 and 11, respectively. Table 6 tabulates the degradation from the SINR for 3/~5 kmph without MS-AAA and the improvement in SINR for various velocities with MS-AAA at CDF of 0.1 for simulation and field experiment. The simulation and experimental results are similar and indicate that the AAA applied to fast moving MS provides significant improvement of SINR in the SDMA mode compared to that in the AAA mode due to the CCI suppression effect. For quantitative discussion, channel characteristic in the experiment needs to be accurately compared to that used for simulation.

B. Results of Normal Drive Test

The measurement condition of the normal drive test is shown in Table 7. We focused on the SDMA mode where the degradation of the down-link performance encountered with the fast moving MS is significant. The CDFs of SINR in the suburban and urban areas are shown in Figs. 12 and 13, respectively. The CDFs of throughput characteristics in the suburban and urban areas are shown in Figs. 14 and 15, respectively. At CDF of 0.1 in the suburban and urban areas, the SINR improvements are 4.5 dB and 3.8 dB, respectively; the throughput improvements are 1.9 times and 1.6 times, respectively; the average throughput improvements are 1.3 times and 1.2 times, respectively. Thus it can be seen that the AAA applied to the MS is effective in various vehicular environments.

6. CONCLUSIONS

In this paper, we have described the developed MS prototype board employing 2-element AAA and evaluated the performance improvement of the down-link under different mobility conditions by the computer simulations and the field experiments in an i-Burst system whose BS employs the AAA and SDMA techniques. In the SDMA mode, we showed significant improvement in SINR values and throughput performance of the down-link at mobile velocity up to about 50 kmph in both the suburban and the urban environments.

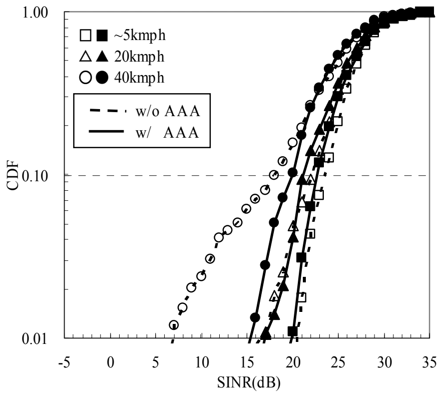

Fig. 10: CDF of SINR in Constant Velocity Drive Test of the AAA Mode.

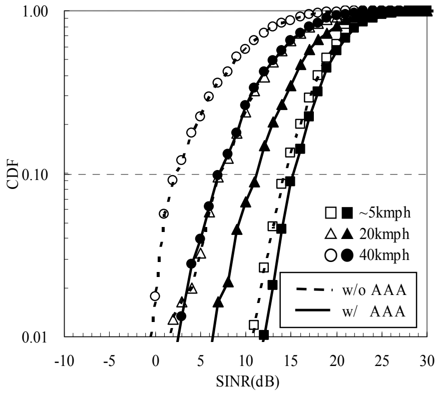

Fig. 11: CDF of SINR in Constant Velocity Drive Test of the SDMA Mode.

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TABLE 7: THE MEASUREMENT CONDITION OF NORMAL DRIVE TEST.

Area	Suburban	Urban
BS antenna height	30 m	25 m
MS antenna height	1 m	1 m
Difference of ground height between BS and MS	0 ~ 28 m	0 m
Distance between BS and MS	0.0 ~1.8 km	0.1 ~ 0.5 km
Velocity	0 ~ 50 kmph	0 ~ 50 kmph

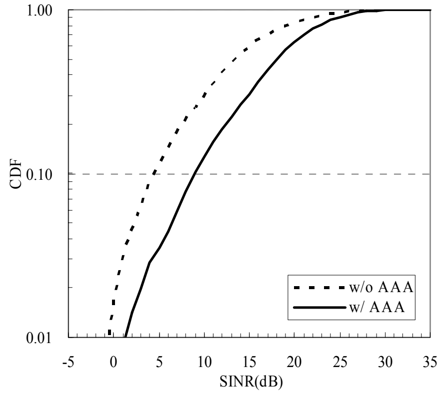

Fig. 12: CDF of SINR in Normal Drive Test of the SDMA Mode (Suburban).

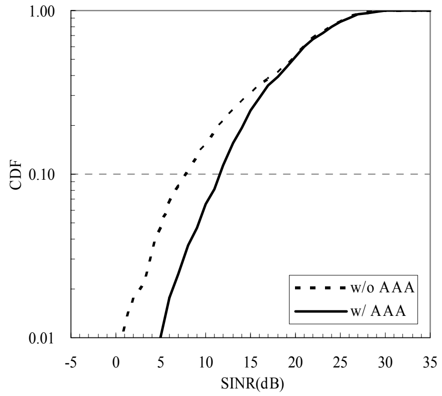

Fig. 13: CDF of SINR in Normal Drive Test of the SDMA Mode (Urban).

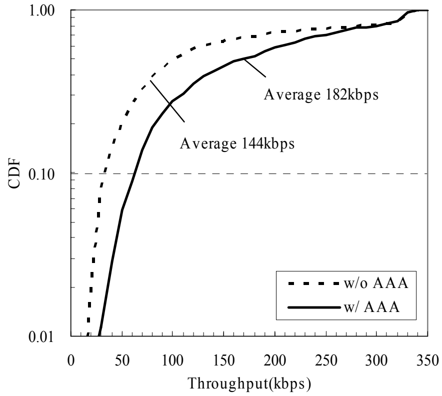

Fig. 14: CDF of Throughput in Normal Drive Test of the SDMA Mode (Suburban).

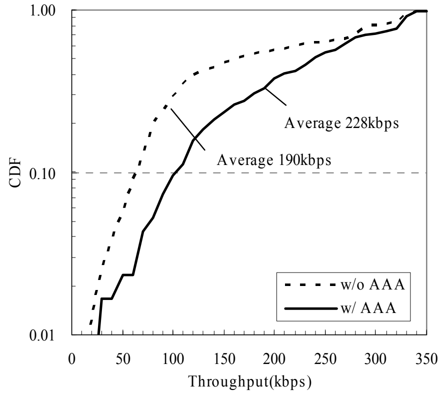

Fig. 15: CDF of Throughput in Normal Drive Test of the SDMA Mode (Urban).

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