Performance Analysis of Smart Antenna Test-Bed Operating in a Wide-Band CDMA Channel

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***Abstract*—In this paper, we present a performance analysis of a smart antenna system operating in a wide-band CDMA wireless-local-loop channel using a beam-forming module (BFM) that has been implemented on a digital signal processor (TMS320C6701) board. We first show the results of computer simulations obtained from the modeled received (RX) signals through a test-bed system consisting solely of baseband signal processing parts, i.e., modeled RX data-generating PC, BFM for computing the optimal weight vector and interfacing module. A test-bed system of the entire base station is then implemented to evaluate the adaptive beam-forming function with the actual wireless signals. This test-bed system includes several subscribers, as well as the array antenna, RF modules, and other receiving parts required at the cell site.**

***Index Terms*—Adaptive array system, experimental data processing, WLL CDMA channels.**

I. Introduction

The smart-antenna system is a composite system consisting of many subsystems, i.e., array antenna, frequency up/down converters, D/A and A/D converter, quadratic mod/demodulators, spreading/de-spreading units, beam-forming module (BFM), coding/decoding units, etc. Unless each of these units works precisely as designed and all the interfaces among the interrelated units work correctly, the entire system never operates as desired.

In this paper we present two smart-antenna test-beds, i.e., test-bed I and test-bed II. In test-bed I, which considers the baseband signal processing units only, the wireless channel, RF modules, and the spreading/de-spreading parts are mathematically modeled in the signal modeling of received (RX) data. The performance analysis of the test-bed is performed in signal environments of the wireless local loop (WLL), based on the modeling, in which there exist a plural number of mobile subscribers, as well as fixed ones. After confirming the validity of the BFM operating in real-time processing based on the modeled RX data in test-bed I, we implement the entire base-station system, i.e., test-bed II, consisting of a six-element linear array, RF modules, BFM, and other baseband signal processing units.

In [1], [2], we proposed efficient adaptive procedures for computing the optimal weight vector for an array system to provide the maximum gain along the direction of the target subscriber in a multipath fading wide-band CDMA channel [6]. All the performances of the smart antenna system shown in this paper have been obtained from the solution of [1] and/or [2].

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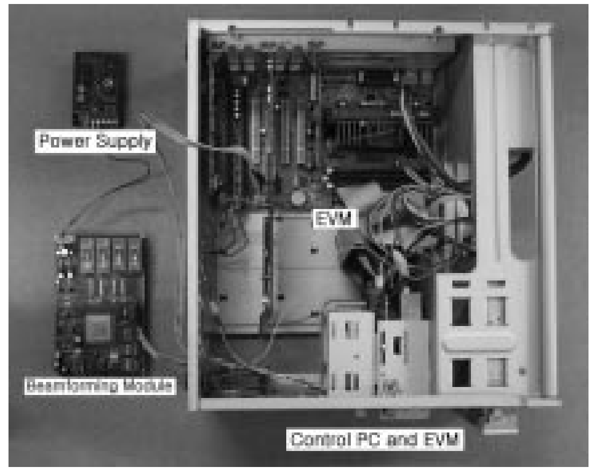

Fig. 1. Smart antenna test-bed system I.

II. Hardware Configuration I

A. System Structure

The test-bed introduced in this section consists of three modules, i.e., a PC (for generating the RX signals based on the signal modeling provided in Section III), an interfacing module (which is implemented with the TMS320C6701 evaluation module (EVM) for interfacing the PC and the BFM) and a BFM (which computes the weight vector from the RX signals). Fig. 1 shows a photograph of the test-bed system I.

B. Beam-Forming Module Implemented With TMS320C6701

This section presents the hardware implementation of the BFM on a standalone printed circuit board (PCB). Fig. 2 illustrates the entire block diagram of the BFM consisting of seven blocks. The first block is the reset block. The second one is the clocking block. Although the maximum CPU clock of the digital signal processor (DSP) is 166 MHz, allowing some margin, we have set the CPU clock to be 133 MHz. The third one is the joint test action group (JTAG) block, which is used to load the adaptive beam-forming algorithm onto the synchronous DRAM (SDRAM) of the BFM or to debug the BFM board. The fourth block is the multichannel buffered serial port (McBSP), which is used to transfer the data between the interfacing module and BFM. The fifth one is the power supplying block. The sixth and seventh ones are the SDRAM and ROM blocks, respectively.

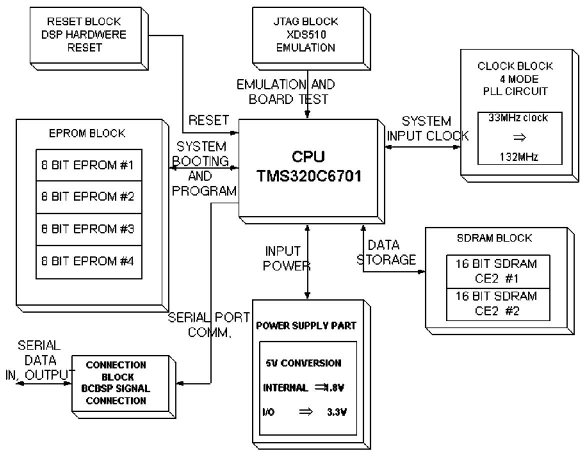

Fig. 2. Entire block diagram of the beam-forming module.

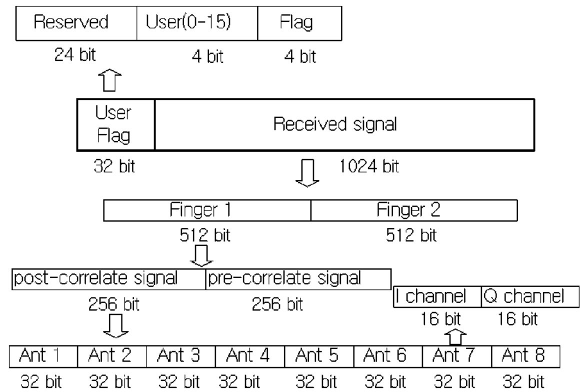

Fig. 3. Data structure of a single data unit.

C. Multiuser Data Structure

In this section, the format of the RX data generated in the PC is defined. Since it is likely that most modules in an actual smart-antenna system will adopt the fixed-point processors, the RX data are prepared in fixed-point in the PC. In fact, in our test-bed, when the weight vector is computed in C6701 (floating-point DSP) of the BFM, the RX data format (fixed point) is converted into a floating point. The computed weight vector is transferred back to the interface module after changing the format back to the fixed point.

It has been found in our previous work [1] that the adaptive procedure computing the solution of the generalized eigenvalue problem is fast enough for the algorithm to provide 32 weight vectors within a snapshot period, which has been set to 1 ms. According to that, our BFM can handle 16 users when two fingers are assigned to each user for Rake reception and it will serve for eight users when four fingers are assigned to each user. In either case, the 16 units of the RX data frame, each of which consists of about 1024 data bits and 32 control bits, should be transferred within a snapshot period of 1 ms. Fig. 3 illustrates the data format of the RX signal used in our test-bed. Out of 32 flag bits in each frame, the 24 most significant bits (MSBs) are reserved and the rest, i.e., eight least significant bits (LSBs) are used for user identification (first four bits) and status representation (the other four bits), respectively. There are 16 896 bits to be transferred through the serial port for each snapshot period, i.e., 1 ms. Thus, about 16 Mb/s is required at the serial port.

III. Performance Analysis I

A. Modeling of WLL Signals

In this section, the data format of the WLL is first introduced together with the analysis of the structural limitations in the performance of the WLL system [4]. The signal modeling is then given for a frequency nonselective multipath fading channel, as noted in Section III-B.

We generate RX data by spreading the pilot and traffic symbols with a PN code. The modulation symbol rate is 128 ks/s and the chip rate becomes 8.192 Mc/s after spreading it with the Walsh code. The PN code of the same chip rate, i.e., 8.192 Mc/s, is then scrambled.

B. Fading Channel Modeling

We consider the multipath fading and angle spread in the signal modeling [3]. We assume L_k small pieces of signal components form a uniform distribution centered at θ_k for the analysis of the angular spread. In this case, the signal induced at the mth antenna element can be written as shown in the equation at the bottom of this page, where J is the number of transmitting subscribers, K_j is the number of multipaths of the jth subscriber, L_k is the number of scattered components at the kth path, $f_{\rm d}$ is the maximum Doppler frequency, $f_{\rm c}$ is the carrier frequency, $\varphi_{j,k,l}$ is the direction of the lth component of the kth cluster with respect to the velocity vector of the jth user, $\tau_{j,k,l}$ is the propagation delay, and $\theta_{j,k,l}$ is the incident angle of the scattered signal. In this section, the following parameters have been used: N (number of antenna elements) $= 8$, $K_j = 2$, $L_1 = 50$, $L_2 = 25$, $f_{\rm d} = 80$ Hz, $f_{\rm c} = 2.3$ GHz. The power ratio between the two paths has been set to 9 : 1.

C. Numerical Results

The performance of test-bed I shown in this section is now analyzed with the RX data generated as shown in Sections III-A and B.

Fig. 4 illustrates the bit error rate (BER) performance with no fading, and Fig. 5 shows the performance in the fading environment shown in Section III-B. To obtain the results of the smart-antenna system shown in Figs. 4 and 5, we load and execute the BFM shown in Section II-B with the adaptive algorithms computing the solution of ordinary [2] and generalized

$$x_m(t) = \left\{ \left(\sum_{j=1}^{J} \sum_{k=1}^{K_j} \sum_{l=1}^{L_k} v_j\,(t - \tau_{j,k,l}) e^{i2\pi(f_{\rm d}\cos\varphi_{j,k,l} t - f_{\rm c}\tau_{j,k,l})} e^{-j(m-1)\pi\ \sin\theta_{j,k,i}} \right) \right\} = +n_m(t)$$

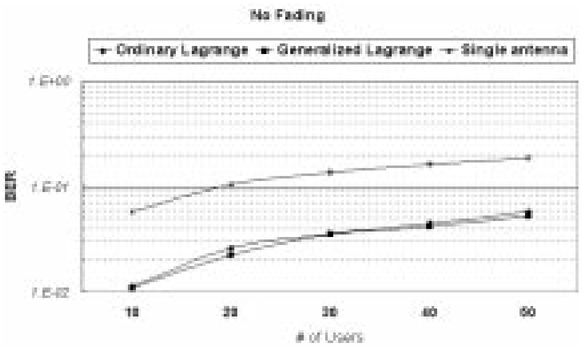

Fig. 4. BER performances in no-fading environments.

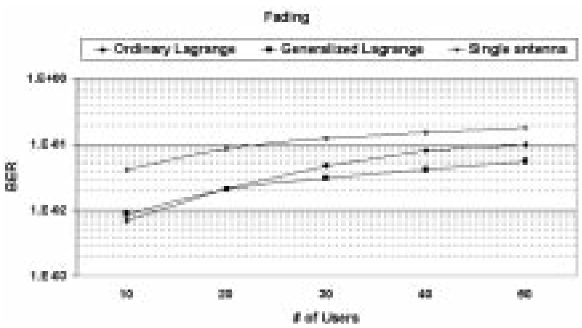

Fig. 5. BER performances in fading environment (faded two multipaths: one 90%, the other 10%).

[1] eigenvalue problem. As the spreading ratio seems to be large enough, i.e., 64, two algorithms are almost comparable in the no-fading environment. In the fading environment, however, the generalized solution outperforms the ordinary solution, especially when the number of interfering users is large.

IV. Hardware Configuration II

A. System Structure

Test-bed I, discussed in the previous section, processes the modeled baseband RX data. The main purpose of it was to check the real-time processing capability of the BFM, i.e., to handle the 32 multipaths within a single snapshot on a single DSP. After confirming that function, it is now possible to deal with more practical RX data received from actual mobile terminals through the wireless paths.

For the experiments, a number of commercial subscribers of the WLL system are used as signal sources of an actual WLL base station that have been modified for our experiments, as shown in Fig. 6. Fig. 7 illustrates the smart-antenna base station developed from the WLL base-station system. This system of test-bed II consists of a six-element (patch type) linear array, commercial WLL base-station system, RX data storage kit, BFM, interfacing module, and three external PCs. As shown in Fig. 6, since the modem part has not been equipped in the test-bed system, the de-spreading procedure is performed in offline processing in the external PCs. The de-spreaded RX data, generated in the external PCs, are sent to the BFM which executes the adaptive algorithm to develop the optimal weight vector in real time. The de-spreading procedure based on the offline processing with a software technique is explained in Section V-B.

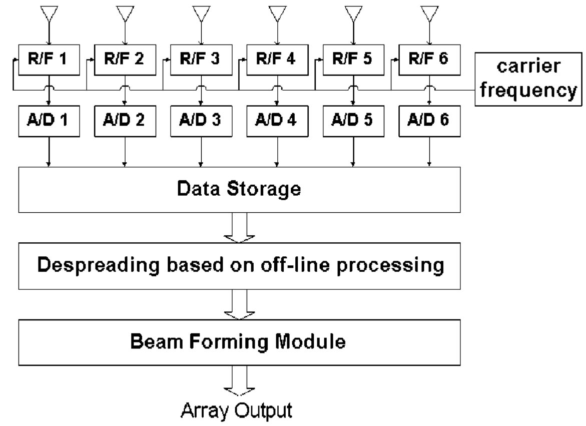

Fig. 6. Block diagram of smart-antenna test-bed system II.

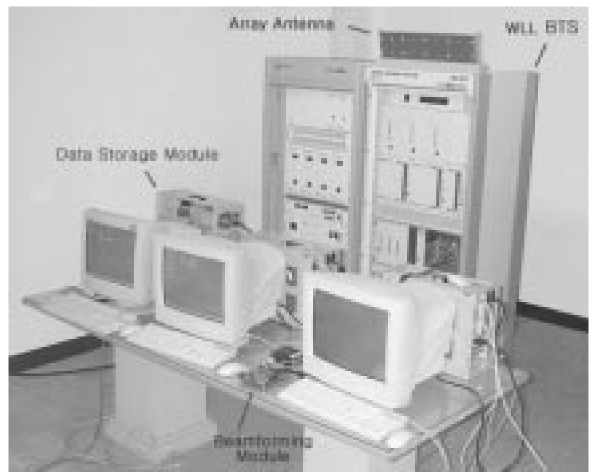

Fig. 7. Smart-antenna test-bed system II.

The number of antenna elements has been chosen to be six in order for us to use the RF modules of the conventional three-sectored WLL base-station system, which has two RX ports at each sector, without any modification. Here, these RF modules are used with our six-element linear array, shown in Fig. 7. The RX RF signal is frequency-down converted in each of the six RF channels with a common local oscillator (LO). The data storage kit is to transfer the A/D converted RX data into the external computers, which perform the de-spreading procedure based on the software programs properly made in accordance with the data format of the WLL system. The de-spreaded RX data are then fed to the BFM to compute the weight vector corresponding to the RX data at each snapshot. The data rate of the RX data is determined as follows:

$$\begin{aligned} 8.192\ \text{Mc/s}\ &\times 4\ \text{(bits/sample)} \\ &\times 4\ \text{(over sampling)} \\ &\times 2\ \text{(I and Q)} \\ &\times 6\ \text{(antenna elements)} \\ &= 1572.864\ \text{Mb/s}. \end{aligned}$$

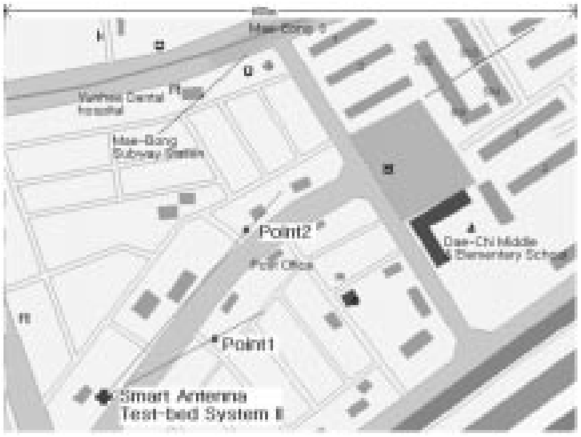

Fig. 8. Location of the smart-antenna test-bed system II and the subscribers.

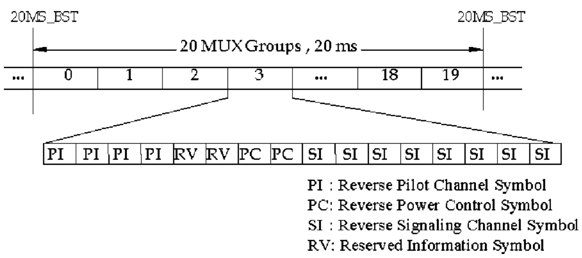

Fig. 9. WLL frame structure (PPCS channel).

Since the capacity of the data storage kit is $16(\text{bit}) \times (32.768\ \text{MHz}) = 524.288$ Mb/s, we needed three PCs to store the RX data. The hardware structure of the BFM and interfacing module of test-bed II are the same as that of test-bed I. There is a minor modification in software.

V. Performance Analysis II

A. RX-Data Measurement Environment

The experiments using test-bed II have been executed in downtown Seoul, Korea, i.e., Do-Gog Dong. A number of remote terminals are used in indoor experiments while a single remote terminal is used as the signal source in outdoor experiment due to legal restrictions. Fig. 8 illustrates the geographical area where the experiments were performed.

B. De-Spreading Based on Offline Processing

The pilot, power control, and signaling (PPCS) channel instead of the traffic channel has been adopted to process the RX data. Details of the RX data have been explained in Section III-A. Fig. 9 illustrates the channel structure of the PPCS [4]. The measured RX data are processed in order to retrieve the transmitted (TX) symbols through the de-spreading procedure [5] as follows.

- *PN Generation*: According to a given PN seed number, a corresponding long PN code is generated with a length of 163 840 chips, which corresponds to the length of a frame length, i.e., 20 ms. The PN code is multiplied by the Hadamard code assigned at each channel in order for each channel to maintain the orthogonality to each other.

TABLE I
BER Analysis in Indoor Experiments

		Desired Signal Power (dB)	SIR (dB)	1 antenna (BER)	6 antenna-Ordinary Lagrange (BER)	6 antenna-Generalized Lagrange (BER)
Case A	1 interferer	-17	-17	0.1954	0.0854	0.0256
Case B		-20	-20	0.3330	0.2287	0.2151
Case C	7 interferers	5	-3.45	0.0711	0.022	0.0193
Case D		-2	-10.45	0.1602	0.0413	0.0363
Case E		-5	-13.45	0.2196	0.0800	0.0838
Case F		-9	-17.45	0.3357	0.2250	0.2521

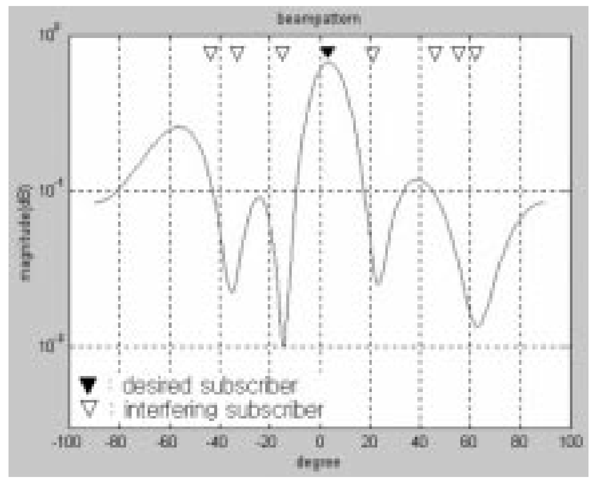

Fig. 10. Beam pattern obtained in indoor experiments.

- *Searching*: In order to find when a peak value is obtained, the A/D converted RX data are shifted by 1/4 chip duration each time. The number of peaks corresponds to the number of multipaths of the given channel.
- *De-spreading*: Utilizing the acquisition of the PN code obtained from the searching procedure, the de-spreading of the RX data, which has been A/D converted, are performed.
- *Channel Estimation*: For the compensation of the carrier phase delay, the phase delay associated with each path is estimated utilizing the pilot channel.

The de-spreaded RX data obtained through the above procedure are used to compute the optimal weight vector in the BFM.

C. Numerical Result

This subsection summarizes the numerical results obtained from test-bed system II in both indoor and outdoor signal environments. For indoor experiments, we consider two cases, i.e., a single-user situation and a seven-user situation. In both cases, we consider six environments, i.e., A, B, C, D, E and F, as shown in Table I. In Cases A and B, the desired subscriber changes its TX power while there exists a single interferer, i.e., a subscriber using the same channel with a different PN code, whereas in Cases C, D, E, and F, the number of interferers is set to seven. Fig. 10 illustrates the beam pattern obtained in Case C. From the results shown in Table I, it can be observed that the smart-antenna system tremendously reduces the BER.

In the outdoor experiments, the desired subscriber's TX power is 0 dB. As we used only one subscriber, i.e., desired one,

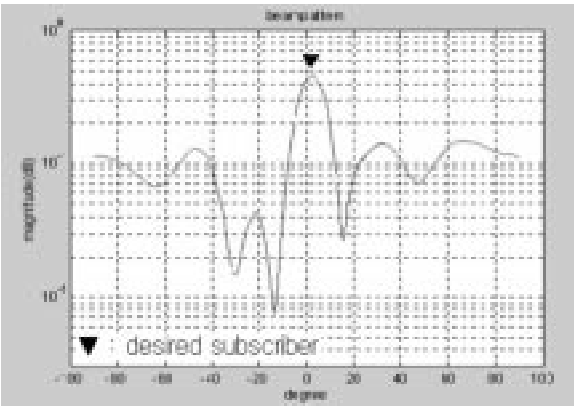

Fig. 11. Beam pattern obtained in outdoor experiments at point 1.

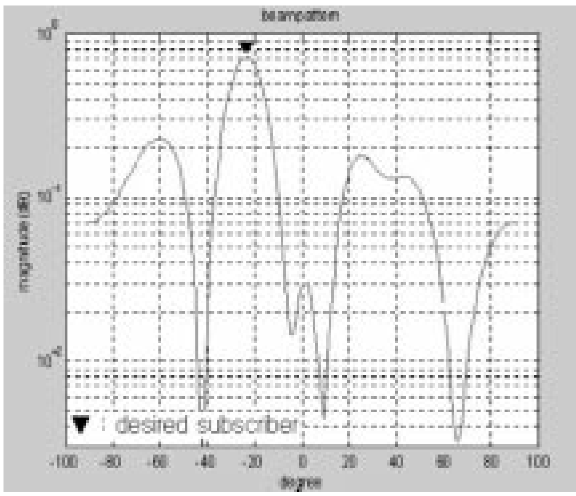

Fig. 12. Beam pattern obtained in outdoor experiments at point 2.

there is no interferer. The location of the subscriber is shown in Fig. 8 as being point 1 and point 2. Figs. 11 and 12 illustrates the beam pattern obtained in these outdoor experiments. From the figures, it can be verified that the smart antenna provides the maximum gain along the direction of the desired signal source.

VI. Conclusion

We have presented two sets of smart antenna test-bed systems for verifying the performance of the adaptive beam-forming capability in real-time processing. Though the experiments have been executed in a WLL CDMA environment, it can easily be observed that the smart-antenna system shown in this paper can straightforwardly be applied to the International Mobile Telecommunications 2000 (IMT2000) for enhancing communication performances.

Acknowledgment

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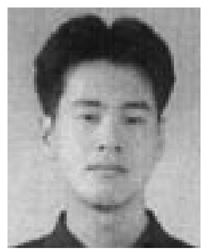

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