PROCEEDINGS OF ISAP2005, SEOUL, KOREA

Downlink Online-Calibration System for Beamforming Base Transceiver Station with Array Antenna

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1. Introduction

Downlink beamforming technology with an array antenna that realizes space division multiple access (SDMA) in downlink is recently proposed to increase a throughput performance per a base transceiver station (BTS) of cellular system [1,2]. The downlink beamforming technology is available to form beam pattern adaptively by controlling relative level and phase among signals transmitted with array antenna. This technology needs an equal number of RF devices consisting of feeder cable and high power amplifier (HPA) including filter with that of antenna elements between a BTS and an array antenna, and there are variation of the level and phase characteristics among the RF devices in practice. Then, the relative level and phase among transmit signals controlled with downlink weighting vector of downlink beamforming is distorted when the transmit signals are radiated from array antenna. In additional, the variation of those characteristics among the feeder cables fluctuates on ground that the characteristic of the feeder cable fluctuates with fluctuation of temperature [3].

In this paper we propose the novel downlink calibration system for beamforming BTS with array antenna. The downlink calibration system allows online-calibration that detects and calibrates the variation of the level and phase characteristics among the RF devices between BTS and array antenna online. This downlink calibration system also needs no special calibration signal. In order to evaluate the proposed downlink calibration system, we developed a calibration testbed system and carried out laboratory experiments in an anechoic chamber, and evaluated calibration control error and the radiation patterns of the downlink beamforming with and without calibration.

2. Downlink Calibration System

In downlink online-calibration system, it is important how to detect variation of level and phase characteristics among RF devices. The proposed downlink calibration system detects level and phase characteristics of each RF device by extracting the input and output transmit signals against RF devices and detecting the level and phase difference of them and obtains the variation of the level and phase characteristics among RF devices.

2.1 System configuration

The block diagram of the proposed

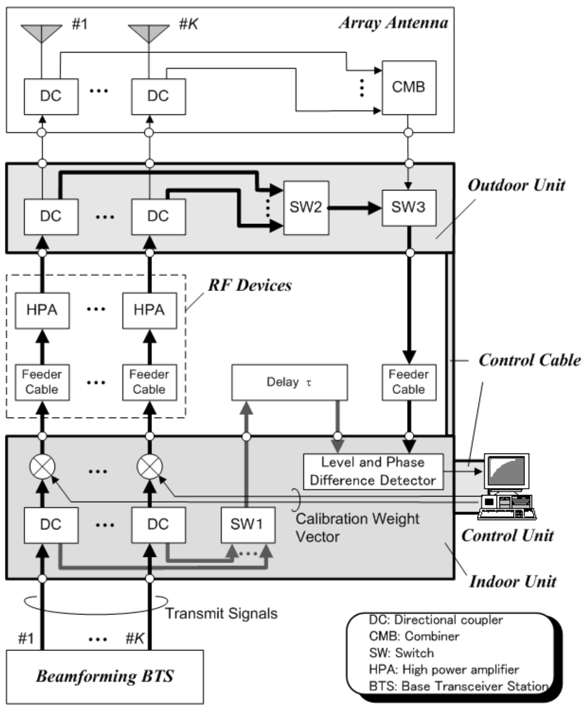


Figure 1 : Block Diagram of Downlink Calibration System.

ISBN: 89-86522-78-0 94460©KEES

downlink calibration system is shown in Fig. 1. The proposed system consists of outdoor unit, indoor unit, and controller unit. The indoor and outdoor units are installed after outputs of beamforming BTS and before inputs of array antenna, respectively, and the RF devices are connected from the outputs of the indoor unit to the outdoor unit.

The indoor and outdoor units have directional couplers (DCs) to extract the input and output signals against the RF devices, respectively. The excluded input signals and output signals against RF devices are switched to 1 signal through switch1 (SW1) and switch2 (SW2), respectively, where the both switches are controlled to extract a signal transmitted through the same RF devices simultaneously and switched by rotation around all RF devices by the control unit. The output signal of SW2 is fed back to the level and phase difference detector in the indoor unit through special feeder cable. Meanwhile, the output signal of SW1 is transmitted through the delay unit to synchronize the both output signals of SW1 and SW2 in the level and phase difference detector.

The detected level and phase characteristics of each RF device in the level and phase difference detector are conveyed to a control unit by rotation around all RF devices. The control unit calculates the variation of level and phase characteristics among RF devices and set the inverse variation as the calibration weight vector. The calibration weight vector is conveyed to level and phase controller in the indoor unit and the variation of level and phase characteristics among RF devices is calibrated.

2.2 Initial offline-calibration

In order to calibrate between the outputs of the beamforming BTS and the antenna elements of the array antenna with high accuracy, this downlink calibration system also operates as initial offline-calibration before above online-calibration to uniform the level and phase in the antenna elements with the even level and phase downlink weighting vector and an array antenna with monitor port shown in Fig. 1.

The initial offline-calibration achieves the calibration with the signal feeding back through an array antenna with monitor port by switch3 (SW3) after SW2. This array antenna has the monitor port outputting the signal combined with the transmit signals extracted before all antenna elements and was developed to calibrate in uplink by inputting the calibration signal into the monitor port reversely. In the initial offline-calibration, beamforming BTS transmits signals weighted with even level and phase downlink weighting vector, and the level and phase controller in indoor unit controls to output only one transmit signal and switch by rotation around all RF devices but set SW2 to some transmit signal. Then the calibration is performed to equal the detected variation of level and phase characteristics of all RF devices with a calibration target vector that is pre-measured the variation of level and phase characteristics between input and monitor port of array antenna when the transmit signals are radiated with even level and phase.

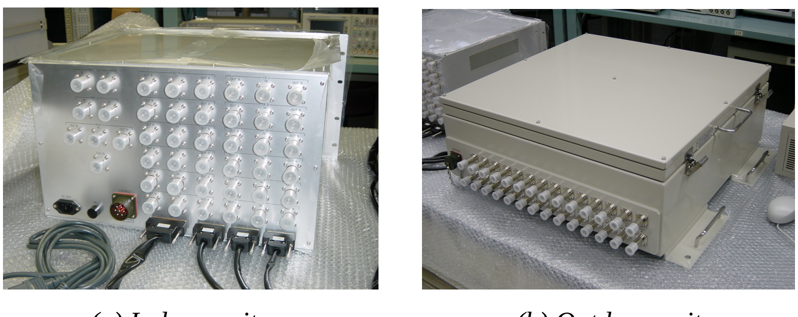
After the initial offline-calibration is completed, the control unit switches SW3 to feed back through the outdoor unit and detects the variation of the level and phase characteristic among RF devices. Then the detected variation is sets as target calibration vector for online-calibration, and the online-calibration starts.

3. Laboratory Experiments

3.1 Experimental system

For evaluation of the proposed downlink calibration system, we developed a calibration testbed system and carried out laboratory experiments in an anechoic chamber. The indoor and outdoor units of the developed calibration testbed system are shown in Figs. 2. The calibration testbed system allows the beamforming BTS with the 12-element array antenna.

The experiment system is shown in Fig. 3. We used a



(a) Indoor unit *(b) Outdoor unit*

Figure 2 : Developed downlink calibration testbed system.

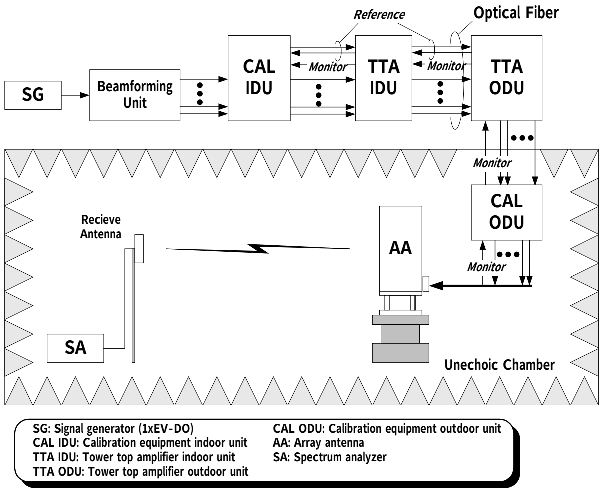


Figure 3 : Experimental system

Table 1: The specification of SDMA packet cellular testbed system

Array antenna	12-element circular array
Antenna element radiation pattern	Directional pattern (Half-power beam width: 60 [deg])
Frequency	Forward link: 2.1 [GHz]
Transmit Signal	1xEV-DO signal
Calibration period	3 [s]

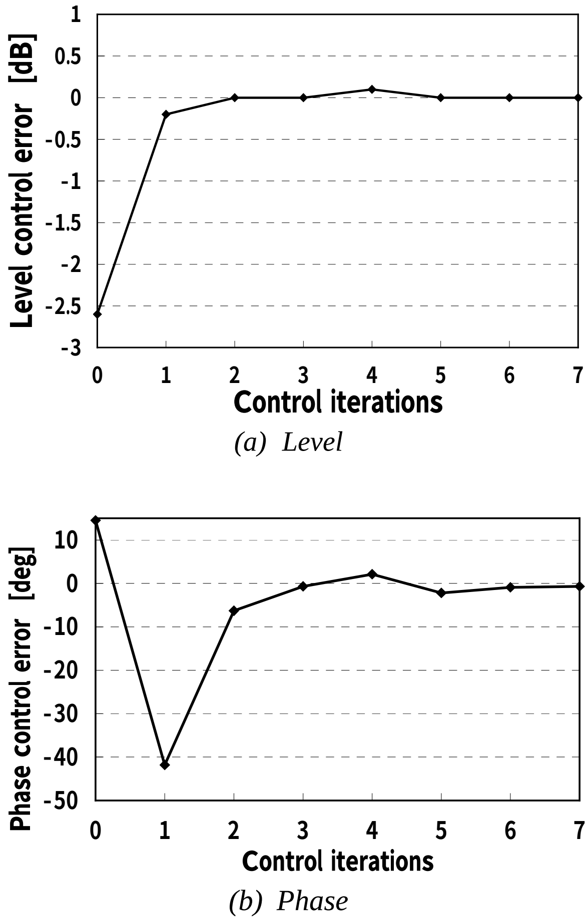


Figure 4 : Calibration control error performances that are the difference of the detected level and phase characteristics of a RF device against the target calibration vector when the initial offline-calibration operated.

signal generator (SG) and a beamforming unit as a substitute for a beamforming BTS. The SG is available to transmit the modulated signal that meets the cdma2000 1xEV-DO standard. The beamforming unit consists of 12-devider and 12 pairs of attenuator and phase shifter. The 12 transmit signals from the beamforming unit are inputted to the indoor unit of the calibration testbed system. The transmit signal outputted from the indoor unit transmit to the outdoor unit through a tower top amplifier system corresponding to RF devices, where the tower top amplifier system including 380m fiber-optic feeder cables laid in indoor environment without the fluctuation of temperature. The array antenna connected from the outdoor unit is 12-element circular array antenna. The antenna elements of the array antenna has directional radiation pattern with half-power beam width equaled to 60 degrees [2].

3.2 Calibration control error performances

The calibration control error performances when the initial offline-calibration operated are shown in Figs. 4 (a) and (b), respectively. Both of horizontal axes are the number of calibration control iteration and the vertical axes in Figs. 4 (a) and (b) are level and phase control error that are the difference of the detected level and phase characteristics of a RF device against the target calibration vector.

In the Figs. 4, it is confirmed that the level and phase control errors converges within 2 control iterations immediately. While the level error converges with 1 control iteration, the phase error converges with 2 control iterations. This is because the level and phase controllers in the indoor unit of the calibration testbed system consist separately and the level controller has phase variation against set level. After convergence, the level and phase errors keep within 0.1 dB and 3 degrees, respectively.

3.3 Beamforming performances

The measured radiation patterns beamformed with the beamforming unit by setting the downlink weighting vector pre-calculated with and without the initial offline-calibration and online-calibration

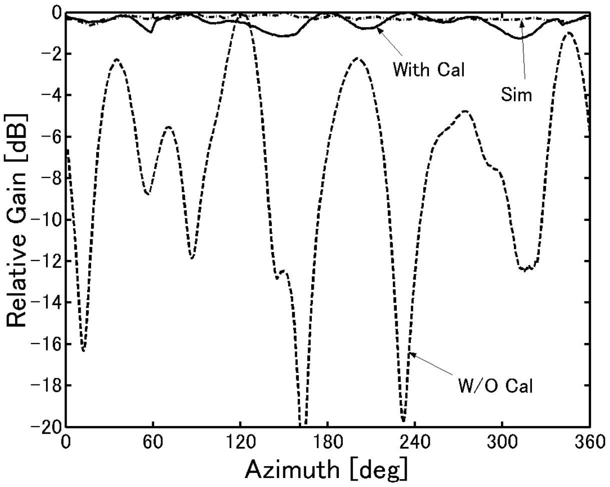


Figure 5 : Radiation patterns when omni-directional beam was formed.

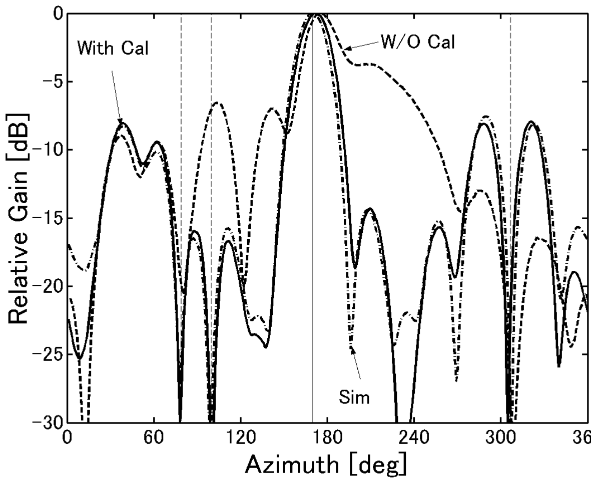


Figure 6 : Radiation patterns when beam and nulls were formed in the direction of 170 degree and {80, 100, 310} degrees, respectively. (the solid and dash gray lines indicate the each directions.)

are shown in Figs. 5 and 6. Both horizontal axes are azimuth in array antenna and vertical axes are relative gain normalized with the max gain. These figures also show simulation results calculated with the set downlink weighting vectors and pre-measured antenna element radiation pattern data [2].

Figure 5 is the radiation pattern when omni-directional beam was formed, where the developed 12-element circular array antenna consisted of directional antenna elements has a feature of forming the omni-directional beam with even level and phase downlink weighting vector. While the radiation pattern without calibration is not formed the omni-directional beam at all, the radiation pattern with calibration is formed omni-directional beam within 2 dB deviation that is almost the same that of the simulation result.

Figure 6 is the radiation pattern when beam and nulls are formed in the direction of 170 degrees and {80,100,310} degrees, respectively. The solid and dash gray lines indicate each directions. While the radiation pattern without calibration is distorted and not formed beam and nulls in the desired directions, the radiation pattern with calibration is formed those just like the simulation result.

4. Conclusion

We have discussed the novel downlink calibration system for beamforming BTS with array antenna and the laboratory experiments. The experimental results prove that the calibration system online-calibrates the variation of level and phase characteristics among RF devices and achieves the high accurate desired downlink beamforming in the radiation from array antenna.

Acknowledgement

The authors gratefully acknowledge the National Institute of Information and Communications Technology (NICT) of Japan for its financial aid to support this research. The authors also express their gratitude to Dr. Y. Yasuda, Dr. F. Watanabe, T. Yokai and Y. Takeuchi of KDDI and President T. Asami of KDDI R&D Laboratories for their valuable comments and continuous encouragement.

References

[1] Y. Amano, T. Inoue, and Y. Karasawa, "Downlink Transmit Beamforming in FDD Cellular System", *WPMC'01*, pp.967-972, Sep. 2001.

[2] Y. Amano, F. Lu, T. Inoue, Y. Takeuchi, "A novel approach for estimating downlink weights for FDD/SDM based wireless packet cellular systems," Proc. WPMC'03, vol.3, pp.425-429, Oct. 2003.

[3] H. Yuan, Y. Amano, T, Inoue, T. Kenmoku, S. Isawa, and T. Yokai, "Experiment Evaluation on the Amplitude and Phase Variation in the Feeder Line and ROF Transmission Line of an Array Antenna Base Station," Proc. of IEICE, vol. J87-B, No.10, pp.1830-1836, Oct. 2004.