

Demodulation of 4x4 MIMO Signal using Single RF

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Abstract— Beam switching in the receiving antenna generates replicas in frequency domain, which enables MIMO decoding by using just single RF. It is fascinating to demodulate MIMO signals using single RF, which relieves the volume expansion by MIMO. However, this scheme has not been verified through a test-bed especially in 4x4 MIMO case.

This paper presents test results of 4x4 MIMO receiver using single RF chain and beam switching antenna. Test results show the constellation and SNR of decoded 4x4 MIMO signal. When beam switching scheme applies, measured SNR was 12.95 dB on average and 17.85 dB at its maximum. This scheme can apply to massive MIMO system which requires quite a number of antennas and RF circuits.

Keywords— Compact, MIMO, Antenna, Beam-switching, ESPAR

I. INTRODUCTION

Massive MIMO is considered a strong candidate technology which shall be used in 5G era. MIMO system requires increased number of antennas and RF transceivers, which brings about significant volume issue, especially in massive MIMO system. There has been significant efforts to reduce the volume of multi-antenna system. To cope with the problems, electrical beam steering antennas have been investigated for a decade. Beam switching scheme is considered a practical form of beam-steerable antenna. We can achieve electrical beam switching by a single active antenna with multiple parasitic elements around it [1]-[5].

It has been revealed that beam switching in the receiver antenna generates replicas in frequency domain, which enables the MIMO decoding by using just single RF. It is fascinating to demodulate MIMO signals using single RF in that such scheme relieves the volume expansion by MIMO. However, most of previous works focused on theoretical analysis and simulations. The beam switching scheme has not been verified so much through a test-bed especially in 4x4 MIMO cases [6], [7]. For the verification of the beam switching scheme, we implemented a test-bed as a proof of concept and carried out tests for demodulating MIMO signal. This paper presents the test results of 4x4 MIMO receiver we implemented in the testbed.

Section II describes the details of designed testbed and test environment. Section III presents test results and analysis of them. We make concluding remarks and discuss issues and further studies in Section IV.

II. TESTBED DESIGN

The test-bed consists of RF, electrically switchable beam-forming antenna, field-programmable gate array, and software for modulation/demodulation. Kintex-7 KC705 evaluation kit is used for real time digital signal processing and Ethernet interface between PC and radio cards with antennas. Radio card contains AD9361 RF agile transceiver, analog-to-digital converter (ADC), digital-to-analog converter (DAC), and PLL's. Radio frequency was tuned to 2.48 GHz in ISM band.

Figure 1 depicts the overall test environment. For transmitting MIMO signal, we used conventional 4 antennas in the test. Electronically steerable passive array radiator (ESPAR) antenna was used in the single RF receiver. The receiver controls the antenna electrically so that the receiving beam switches to 4 directions sequentially. Beam switching speed depends on the symbol rate and the number of beam directions to switch.

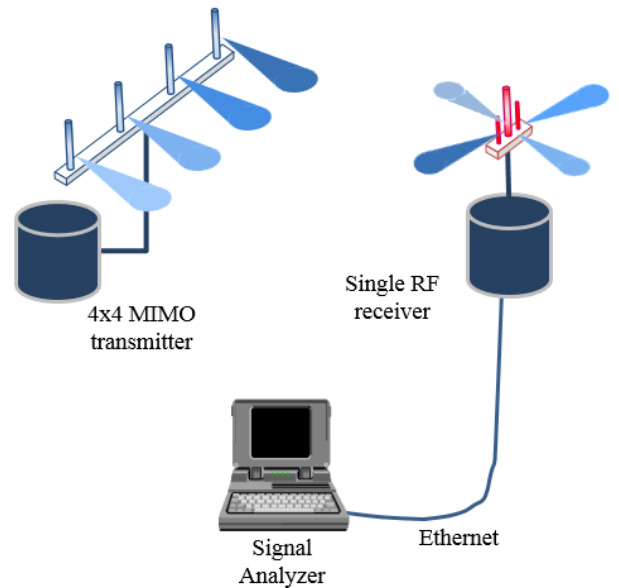


Figure 1. Test environment

Signal analyzer collects base band I/Q samples from the single RF receiver via Ethernet link. It does not need signals from 4 antennas but only one antenna. This is the key

difference from the conventional scheme. The analyzer demodulates the collected I/Q samples and calculates the signal to noise ratios (SNR's) of 4 signal layers. We used a conventional zero forcing receiver scheme to decode MIMO signal.

Transmitter sends 960 kbps binary phase shift keying (BPSK) signal at each antenna. Figure 2 shows the frame structure of the signal of all antennas used in the test. Pilot is for synchronization at the receiver. Reference signals (RS's) in front of data is for MIMO decoding. One frame is 100us long. Super frame consists of 5 frames and transmitter repeats to sends the super frames continuously.

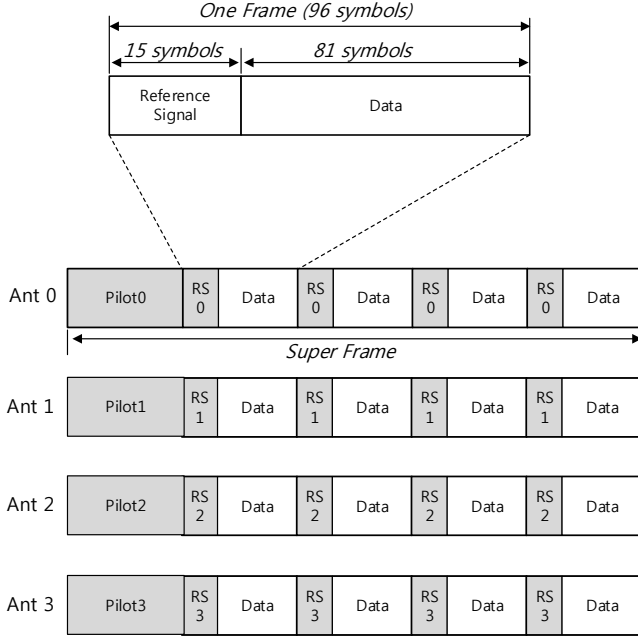


Figure 2. Frame structure of the signal used in the test

III. TEST RESULTS AND ANALYSIS

A receive antenna at a distance of 2 meters from the transmitting antenna switches among 4 directional beams at 3.84 MHz rate to recover 960 kbps BPSK symbols at each receiving beam. Thereby, beam controller switches the beam direction at 15.36 MHz rate. Totally 3.84 Mbps information can be delivered with single RF with 4 beams at maximum. The test was carried out indoors at 2.48 GHz in ISM band. Transmit power measured at each antenna port is about -8 dBm.

Test results showed that measured SNR of the recovered signal varies from 13 to 20 dB, which guarantees bit error rate (BER) under 10^{-4} in additive white Gaussian noise (AWGN) channel [4]. We assume that the measured SNR depends on the channel effect such as delay spread and interference. Figure 3 shows the captured constellation of the recovered I/Q signal. Their SNR's were measured to 13.4, 20.8, 15.7, and 18.2 dB, respectively at each MIMO path. In this case, mean

value of 4 SNR's is 15.9 dB. According to the test results, measured SNR was 12.95 dB on average and 17.85 dB at its maximum when beam switching scheme applied to the receiver of testbed.

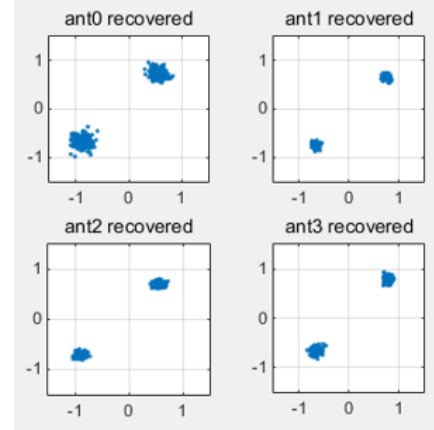


Figure 3. Constellation of recovered I/Q (single RF)

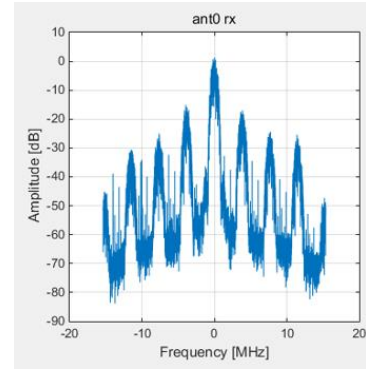


Figure 4. Spectrum of received signal (single RF)

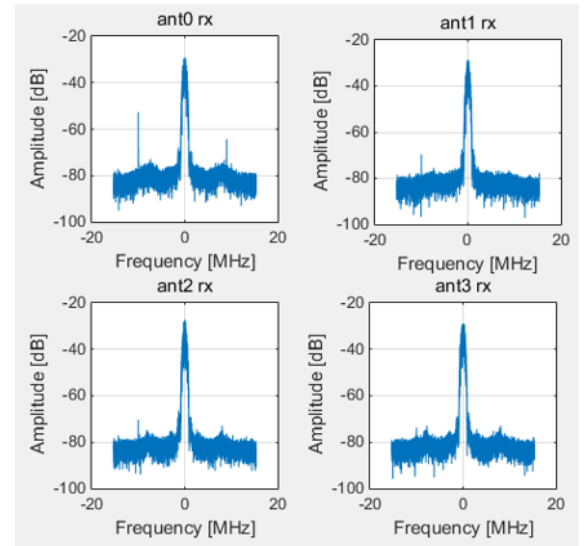


Figure 5. Spectrum of received signal (conventional MIMO)

Figure 4 shows the spectrum of the received signal at the single RF. We can see the spectrum spreading which is the nature of beam switching receiver. We recommend to see more about the analysis of the spectrum spreading in [6] as it is not the scope of this paper. Each lobe in the spectrum is considered a received signal from different antenna, thereby it suffered different channel effects. Once four lobes are selected, we can decode 4x4 MIMO signal by using conventional decoding scheme. This paper adopted zero forcing scheme.

As a performance comparison, we carried out tests with conventional MIMO receiver consisting of 4 antennas. Figure 5 shows the spectrums of all received signals from 4 antennas. Test results showed that measured SNR of the recovered signal is 15.45dB on average, which is 2.5 dB better than beam switching scheme. This implies that there should be margins to enhance the performance of beam switching receiver scheme. Figure 6 shows the captured constellation recovered by conventional MIMO receiver. Their SNR's were measured to 11.3, 15.6, 22.5, and 17.7 dB, respectively at each antenna.

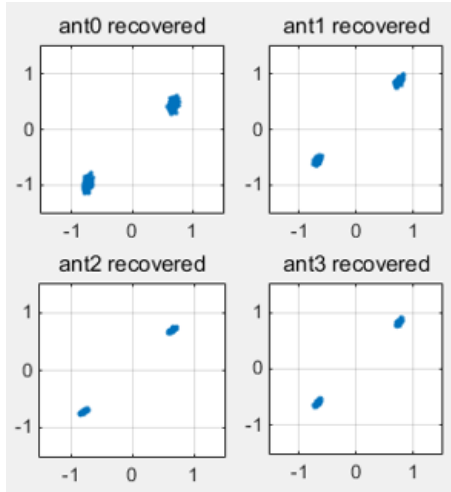


Figure 6. Constellation of recovered I/Q (conventional MIMO)

IV. CONCLUSIONS

This paper presented experiment results implying that 4x4 MIMO signal can be demodulated by beam switching scheme with single RF. Test results in this paper was anticipated in the former studies theoretically, and this paper verified the theory through the experiment.

Although it is fascinating to demodulate MIMO signals using single RF, which relieves the volume expansion by MIMO, we noticed some margin to enhance the performance because we still seem to have factors degrading SNR. The factors shall be the ambiguity residues in transient time for beam switching, antenna gain, and demodulator algorithm. Our further study shall focus on the performance enhancement by diminishing the bad factors. Transient time can be diminished by using fast switching devices. Antenna gain can

be enhanced as well. With the improved SNR, we will be trying to decode OFDM signal based on 3GPP LTE.

We hope this results apply to massive MIMO system which requires normally quite a number of antennas and RF circuits in the near future.

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