Experimental Studies of SDMA Schemes for Wireless Communications *

H.P. Lin, S.S. Jeng, I. Parra, G. Xu, W.J. Vogel, and G.W. Torrence
Electrical Engineering Research Lab.
J.J. Pickle Research Center, UT-Austin
Austin, TX 78758-4445
Tel: (512)471-6168, Fax: (512)471-8609

Abstract

This paper presents some preliminary results of experimental studies of Space-Division-Multiple-Access (SDMA) systems for wireless communications to expand capacity, increase coverage, and improve quality. Although the SDMA schemes have been studied by a number of researchers (see *e.g.*, [1, 2, 3]), most of these studies are based on theoretical analyses and computer simulations. Very few real RF or microwave experiments have been conducted to validate the feasibility of various signal processing algorithms, such as direction finding and signal copy techniques. Also, no extensive experiments have been conducted to study the channel propagation associated with multiple antennas. The purpose of this paper is to present our preliminary experimental results using our recently developed antenna array testbed. We will also discuss the implications of these results on various array signal processing algorithms.

1 Introduction

The current wireless communication systems will soon become incapable of meeting the projected immense demand. Besides the capacity problem, the drastic increase of radio traffic would also create new problems and worsen the existing difficulties, such as multipath, channel reuse among neighboring cells, near-far receiving problems, handoff from one cell station to another, limited battery life for pocket handsets *etc.* The space-division-multiple-access (SDMA) scheme has been proposed to increase the channel capacity via exploiting spatial diversity among different mobile users. Although many existing and new array signal processing techniques are proposed for the SDMA scheme, most of the performance evaluation rely on computer simulations or theoretical analyses based on ideal assumptions. In this paper, we present some preliminary experimental results of channel propagation effects and the feasibility of various SDMA schemes. In following, we shall present our experimental results concerning stability of array response vectors (or the so-called *spatial signatures* (SS) for fixed and moving transmitters, direction-of-arrival (DOA) estimation, array response vectors for different carriers, and transmission beamforming.

*This work was partially supported by National Science Foundation under contract ECS-9310718, Southwestern Bell Technology Resources, Motorola, Inc, and University Research Institute of UT-Austin.

2 Experiment Setup

The following experiments were carried out using our recently completed testbed comprised of the following subsystems: (1) One 8-element patch antenna array and four 1-element dipole antenna. The 8-element patch antenna array are arranged in a linear fashion with separation about half wavelength for base station. Four dipole antenna are used as mobile users. (2) 12 RF and IF up/down converters and switches with RF band operating around 900 MHz/ 2.4 GHz and IF band operating around 144 MHz. (3) Two distribution boxes providing synthesized sources for RF and IF local oscillating signal. (4) 12 A/D's and 24 D/A's. The 12 sets of 8-bit A/D converters can sample up to 15 MHz, Although our current setup has the following sampling rate: 5 MHz, 2.5 MHz, 1.25 MHz, 625 KHz, 312.5 KHz, 156.25 KHz, 78.13 KHz and 39.06 KHz. Each D/A converter has the following sampling rate: 2.5 MHz, 1.25 MHz, 625 KHz, 312.5 KHz, 156.25 KHz, 78.13 KHz, 39.06 KHz and 19.53 KHz in the current setup. (5) 4 digital multiplexing (MUX) and demultiplexing(DEMUX) boards. Each MUX/DEMUX board is connected to one of two high speed I/O boards installed in the s-bus slots of a Sparc 10 workstation. (6) High speed I/O boards and Sparc 10 workstation. Two I/O boards have been installed in Sparc 10 workstation. Each board can read/write from/to the Sparc 10 memory at a speed up to 40 MB/s independently. The console of our testbed is a Sparc 10 model 51 workstation with about 1GB hard disk and 96 MB memory.

0-7803-2431-5/95 $4.00 © 1995 IEEE

3 Experimental Results

In the following, we shall show our experimental results conducted at J.J. Pickle Research Campus of The University of Texas at Austin.

3.1 Spatial Signatures of Fixed and Moving Emitters

A spatial signature is the array response vector of the antenna array to an emitter at a certain location. In a typical wireless communications scenario, different mobile users are located in different positions and thereby have different spatial signatures on the antenna array at the base station. Exploiting the difference of spatial signatures, we can selectively receive and transmit multiple co-channel signals without interfering one another. This is the basic idea of the so-called *smart antenna* system. To demonstrate the feasibility of this idea, we measured the spatial signatures of a fixed emitter over 10 hours to test its stability. The results are shown in Figure 1-2. From these results, we can see that the spatial signatures do not vary significantly over a long period of time as long as the mobile unit is stationary. Some spikes in Figure 1 may correspond to moving objects due to wind or moving vehicles. We also measured the spatial signatures of a moving emitter. We took four random snapshots while the emitter was moving in a small region (about $\pm 5°$). The results are shown in Figure 3-4. It is easily seen that the spatial signatures are very sensitive to the position changes of the mobile user, which suggests that we need to update the spatial signatures very frequently in the SDMA scheme. More detailed studies are being carried out to quantify the update rate for different scenarios.

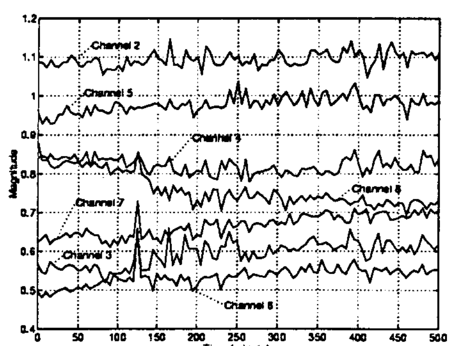

Figure 1: Magnitude of the Spatial Signature Measurements of a Fixed Emitter

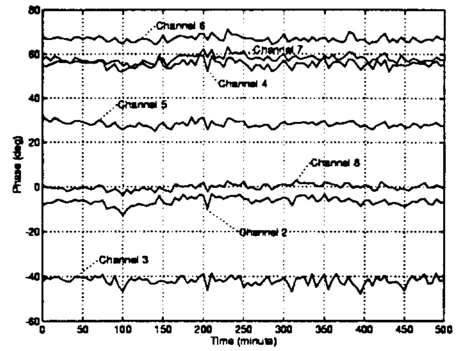

Figure 2: Phase of the Spatial Signature Measurements of a Fixed Emitter

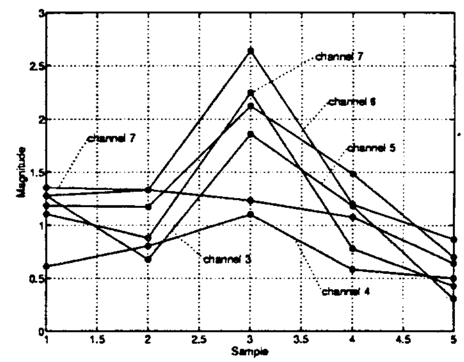

Figure 3: Magnitude of the Spatial Signature Measurements of a Moving Emitter

3.2 Feasibility of Direction Finding

High-resolution direction finding algorithms (*e.g.*, MUSIC [4] and ESPRIT [5] were proposed as one means of finding the spatial signatures. Knowing the DOAs of the mobile users and their multipath, we can also construct downlink spatial signatures and eventually design-weighting vectors [6, 7] to achieve transmission beamforming. The feasibility of this approach relies on the number of multipath signals. If there are too many multipath components for each source, then the direction finding approaches may not succeed. In the experiment, we placed the emitter around 9 points around the antenna array and the results are shown in Table 1. The number of multipath signals is not very large (maximum 3). Therefore, the direction finding algorithms may be used in outdoors environments, especially in rural environments.

3.3 Spatial Signature Variation with the Carrier

Since in cellular systems, the downlink and uplink frequencies have about 45MHz difference. It would be

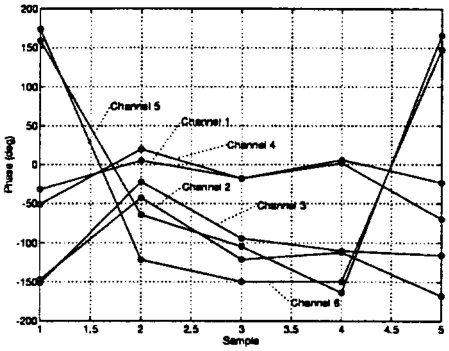

Figure 4: Phase of the Spatial Signature Measurements of a Moving Emitter

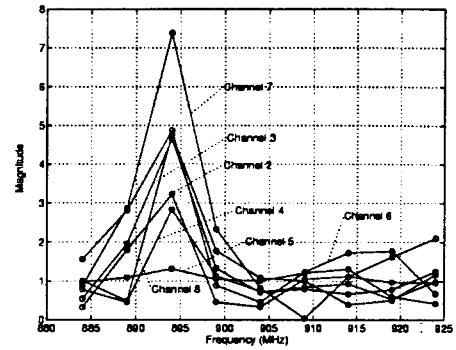

Figure 5: Magnitude of the Spatial Signature Measurements for Different Carriers

True DOA	DOA #1	DOA #2	DOA #3	DOA #4
$-45°$	$-48.72°$	$22.09°$	$80.10°$	$-15.21°$
$-30°$	$-29.64°$	$28.58°$	-	-
$-20°$	$-18.90°$	$32.14°$	$-74.39°$	-
$-10°$	$-10.03°$	$31.05°$	-	-
$0°$	$-0.04°$	$28.87°$	-	-
$10°$	$6.38°$	$34.81°$	$-22.07°$	-
$25°$	$23.36°$	$-39.05°$	-	-
$40°$	$39.91°$	$-75.02°$	$-0.44°$	$-30.09°$
$50°$	$50.50°$	$23.39°$	$-28.15°$	-

Table 1: DOA Measurements of Direct Path and Multipath Signals

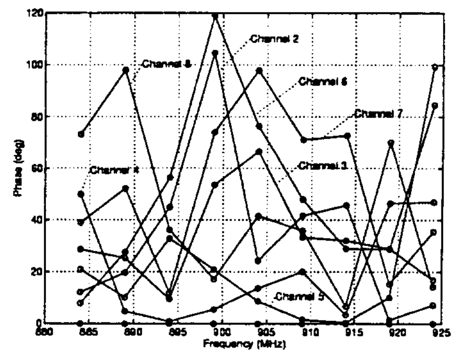

Figure 6: Phase of the Spatial Signature Measurements for Different Carriers

interesting to find out the difference of the spatial signatures for slightly different frequencies. This result can show the feasibility of using uplink spatial signatures for selective transmission of in the downlink. In the experiment, we fixed the transmitter and vary the carrier frequency from 884MHz to 925MHz. Figures 5-6 show the variations of spatial signatures with the carrier. Obviously, the carrier variation is quite significant even for a small percentage change of the carrier. This also means that the uplink spatial signatures cannot directly used for downlink beamforming in a frequency-division-duplex (FDD) system.

3.4 Feasibility of Downlink Beamforming

In time-division-duplex (TDD) systems, such as CT-2 and DECT, the carriers for uplinks and downlinks are the same. In this case, the uplink spatial signatures obtained from the blind type algorithms can be directly used for downlink beamforming. In the experiment, we formed the weighting vectors based on the uplink spatial signatures and transmit two tones. Figures 7-8 show the spectra of two signals received by two mobile users. The co-channel supression achieved by downlink beamforming is quite significant for two closely spaced sources. In frequency-division-duplex (FDD) systems, such as GSM, IS-54, and IS-95, the uplink and downlink frequencies are significantly different (45MHz apart). In this case, we must construct the beamforming weights according to the directions-of-arrival (DOAs) of all the sources. We also implemented a simple weight design method, *i.e.*, taking the pseudo inverse of a matrix with the *steering vectors* corresponding to all the direct path and multipath DOAs. The results are shown in Figures 9-10. The result for 20° separation (as shown in Figure 9 is comparable to that in Figure 7, while the result for 3° separation (as shown in Figure 10 is much worse that in Figure 8, since the DOA-based beamforming has resolution limitation.

4 Concluding Remarks

In this paper, we have presented preliminary results of experimental studies of SDMA schemes and their associated techniques. We have also conducted several experiments to study the channel propagation effect on an antenna array.

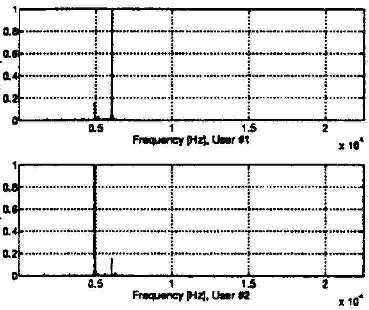

Figure 7: SS-based Beamforming Results for Two sources with Separation about 20°

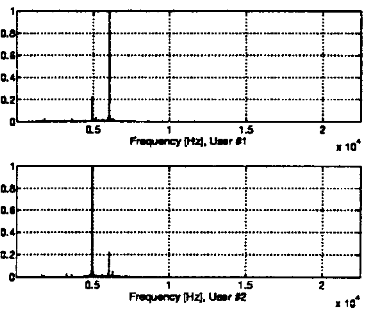

Figure 8: SS-based Beamforming Results for Two sources with Separation about 3°.

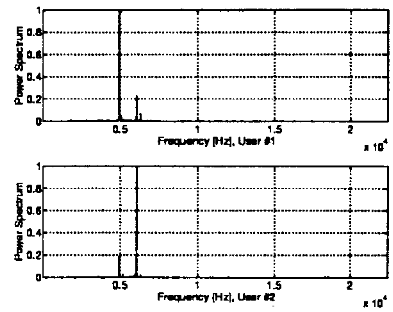

Figure 9: DOA-based Beamforming Results for Two sources with Separation about 20°

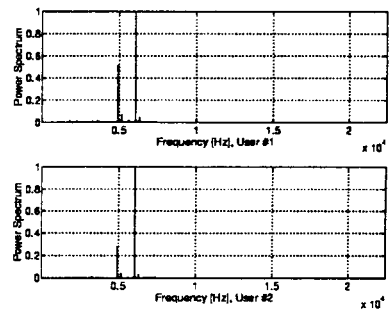

Figure 10: DOA-based Beamforming Results for Two sources with Separation about 3°.

References

[1] S.C. Swales, M.A. Beach, D.J. Edwards, and J.P. McGreehan, "The Performance Enhancement of Multibeam Adaptive Base-Station Antennas for Cellular Land Mobile Radio Systems", *IEEE Trans. on Vehicular Technology*, **39**(1):56–67, Feb. 1990.

[2] G. Xu, Y. Cho, A. Paulraj, and T. Kailath, "Maximum Likelihood Detection of Co-channel Communication Signals via Exploitation of Spatial Diversity", In *Proc. of the 26th Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, Oct. 1992.

[3] J.H. Winters, J. Salz, and R.D. Gitlin, "The Capacity of Wireless Communication Systems Can Be Substantially Increased by the Use of Antenna Diversity", In *Proc. of Conference on Information Science and Systems*, Princeton, NJ, March 1992.

[4] R.O. Schmidt, *A Signal Subspace Approach to Multiple Emitter Location and Spectral Estimation*, PhD thesis, Stanford University, Stanford, CA, November 1981.

[5] A. Paulraj, R. Roy, and T. Kailath, "A Subspace Rotation Approach to Signal Parameter Estimation", *Proceedings of the IEEE*, **74**(7):1044–1045, July 1986.

[6] B. Ottersten, R. Roy, and T. Kailath, "Signal Waveform Estimation in Sensor Array Processing", In *Proc. 23rd Asilomar Conference on Signals, Systems, and Computers*, volume 2, pages 787–791, Pacific Grove, California, November 1989.

[7] R. Roy, G. Xu, and T. Kailath, "Robust Beamforming with Unknown Directions-of-Arrival", In *Proc. of 1991 Underwater Acoustic Signal Processing Workshop*, Kingston, RI, Oct. 1991.