

# Recent Results from Smart Antenna Experiments -- Base Station and Handheld Terminals

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**Abstract:** *Virginia Tech is involved in both smart base station and smart terminal antenna research for wireless applications. Smart features vary from simple diversity combining to adaptive algorithm implementations. Measurement campaigns are described and results are presented.*

## 1. Smart Base Station Experiments for Space, Polarization, and Angle Diversity Comparisons.

### 1.1. Introduction

Diversity techniques are used at the base station to overcome multipath fading. Although space diversity is the most common form of antenna diversity, it is the least attractive because it requires a second antenna subsystem. A separate diversity antenna requires space and cable runs, and increases installation and maintenance costs significantly. The remaining diversity choices are angle and polarization diversity. Recent interest has focused on polarization diversity that uses a single dual polarized antenna in place of two space diversity antennas [1]. Angle diversity with switched-beam antennas is also effective in urban environments [2], but its performance with indoor mobile users has not yet been reported. No direct, simultaneous performance comparisons of space, polarization, and angle diversity have been reported. This paper reports on measurement campaigns being conducted by the smart antenna group at Virginia Tech with both base station and handheld smart antennas.

### 1.2 Smart Base Station Testbed and Measurement Environments

The experiment hardware consists of a base station on the top of a six-story campus building (30 m tall) that is surrounded by other buildings and the coverage area within several kilometers is a dense urban environment. The smart base station testbed has three antenna subsystems. Two sector antennas each with 95° azimuth beamwidths are spaced ten feet apart, forming the space diversity antenna subsystem. A single dual-polarized, slant 45° panel antenna with 90° beamwidths provides two channels for polarization diversity. Angle diversity is obtained with a panel antenna that covers 120° of azimuth with four 30° beams. The three diversity antenna subsystems provide

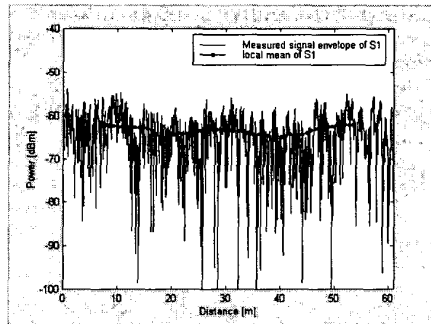
coverage of the same azimuth region and all have a vertical beamwidth of about 15°. The eight base station outputs (two each for spatial and polarization diversity, and four for angle diversity) provide signals that are coherently received.

The mobile unit, moving at the speed of about 1~2 m/s, transmits a continuous wave signal at 842 MHz. The eight RF signals received at the base station are down converted to a 1.2 kHz IF using RF mixers with the same local oscillator which maintains the relative amplitude and phase information between channels. The IF signals are recorded with a 16-bit A/D converter running at the sampling rate of 6.25 kHz per channel and then are post-processed in non-real time.

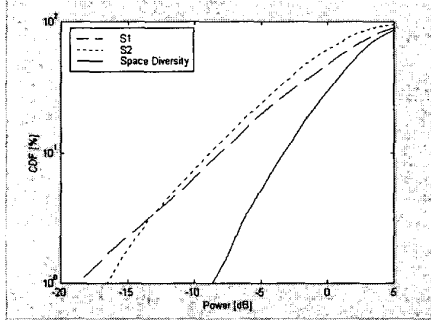
Measurements are made for various mobile transmit unit locations using a half-wavelength dipole antenna in three orientations: (a) vertical (V), (b) horizontal and orthogonal to the direction of movement (H+), (c) horizontal and parallel to the direction of movement (H||). The operator of mobile unit is equipped with a cellular phone for voice communication with the operator at the base station. All measurements are performed along the straight routes. Measurement runs are performed over distances of 60 to 110 m for the outdoor environments and 35 to 50 m for the indoor environments. The average velocity of the mobile unit was calculated using the measured distance and time for every run. The distance between mobile unit and base station is measured using the GPS receiver after selective availability signal is turned off and is ranging from 150 m to 5 km.

### 1.3 Initial Results

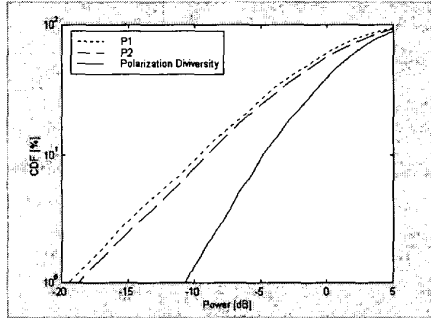
Figure 1 shows representative results of the measured signal envelope for one channel and cumulative distribution functions (CDF) for selection combining using a vertically polarized mobile unit antenna 665 m away. Several measurements at various distances and sites with three orientations of mobile unit antenna were performed. Table 1 summarizes the measurement results performed at three example locations.



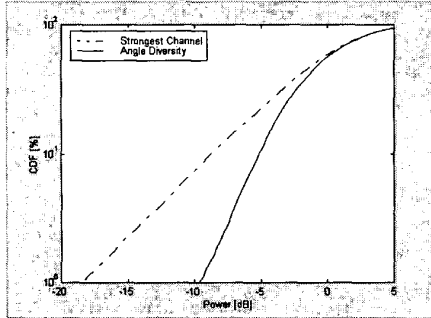
(a) Measured signal envelope of one channel



(b) CDF for space diversity



(c) CDF for polarization diversity



(d) CDF for angle diversity

**Figure 1.** Signal envelope and CDF's for three kinds of diversity under the identical condition

Diversity gain is the primary figure of merit and is the increase in signal level on the CDF from single antenna to diversity antenna performance at a given occurrence level. Measured results at the distance of 665 m showed that the diversity gain for the three diversity schemes are close to each other at 1 % level of CDF regardless of the orientations of mobile unit antenna. Although polarization diversity gains are close to the other kinds of diversity gains, the performance of polarization diversity is superior when the mobile unit antenna is horizontal and is worse with vertical orientation due to the polarization match. At the distance of 935 m, space diversity gain is slightly better than that for the other kinds of diversity regardless of the orientations of mobile unit antenna. At the distance of 2,670 m, space diversity gain is slightly better than polarization diversity gains and several dB better than angle diversity gain regardless of the orientations of mobile unit antenna. The measurement campaign is still in progress.

**Table 1.** Diversity gains at three representative locations (units in dB)

Dist.	Pol. CDF (%)	V		H+		H	
		10	1	10	1	10	1
665 m	S	5.2	8.9	5.2	9.7	5.7	10.9
	P	4.5	8.4	3.8	6.6	5.1	8.9
	A	3.6	8.7	2.5	8.3	3.6	9.0
935 m	S	4.8	8.9	5.1	9.8	5.1	9.3
	P	4.6	8.2	5.2	10.1	4.5	8.5
	A	3.1	7.8	2.2	6.1	3.0	7.6
2670m	S	5.5	10.2	5.5	10.7	5.7	10.0
	P	4.7	8.5	5.1	9.7	5.1	9.4
	A	1.5	6.3	0.9	4.6	1.7	6.6

## 2. Handheld Adaptive Arrays

### 2.1 Introduction

The popularity of the wireless bands has led to communication traffic increases that often limit system performance due to interference. Handheld radios with adaptive antennas can reject interference, and thus improve communication link quality and increase system capacity. However, little research in this area has been reported for commercial communications. In 1988, Vaughan [3] concluded that adaptive beamforming could be implemented for units moving at pedestrian speeds. Lian [4] considered the possibility of using handheld adaptive antennas in mobile satellite networks. In 1999, Braun, et al. [5] reported on indoor experiments in which data were recorded

using a stationary narrowband transmitter and a two-element handheld receiving antenna array. In [5], data recorded over different paths were treated as desired and interfering signals, and the uncorrupted desired signal, unavailable in practice, was used as a reference signal for optimum beamforming. While these experiments do not correspond to actual operating conditions, interference rejection of 24 dB in the single-interferer case and 16 dB in the two-interferer case was reported in two handset configurations.

The Smart Antenna Group at Virginia Tech has performed an extensive investigation of adaptive beamforming using compact antenna arrays on a handheld radio platform. The investigation uses small four-element antenna arrays mounted on a receiver that could be carried like a mobile phone. Experiments show that a high degree of interference rejection is possible, indicating that in a system using handheld radios equipped with adaptive arrays, more than one user can share a frequency channel during the same time slot. This can be accomplished through a spatial-division multiple access (SDMA) scheme or a combination of SDMA and code division multiple access (CDMA). Capacity improvement allows a commercial mobile communication system to support more users than a conventional system using the same limited frequency spectrum, resulting in increased revenues. The interference rejection capability of handheld adaptive arrays also provides protection against jamming in military scenarios.

## 2.2 Experiment Description

The adaptive beamforming measurement campaign consists of over 250 experiments in rural, suburban, and urban channels with two mutually interfering transmitters. Performance of single-polarized and multi-polarized four-element compact arrays is measured in outdoor peer-to-peer (distances of 25-50 m, line-of-sight and non line-of-sight) and microcellular (distances of up to 0.6 km, mostly non line-of-sight) scenarios. Figure 2 shows the testbed system in a typical experimental scenario. In each measurement, two fixed transmitters transmit approximately equal-level continuous wave (CW) signals offset by 1 kHz at approximately 2.05 GHz. In some experiments the receiver is alternately connected to five small 4-element array configurations and is moved along a 2.8 m track to provide consistent results. In other measurements an operator carries the receiver and antenna array next to his head to represent a realistic operational scenario. A direct conversion 4-channel receiver is used that mixes the received

signals down to baseband. The data are recorded on two portable stereo digital audiotape recorders at 32,000 samples per second per channel, 16 bits per sample. A pulse is recorded at the beginning and end of each measurement to align the data for processing.

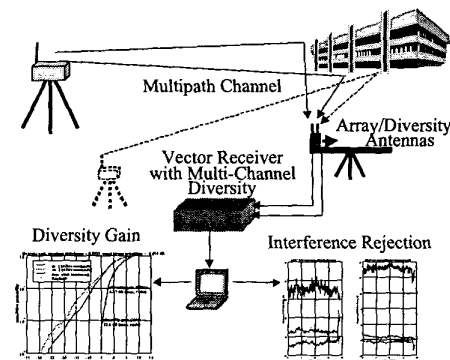


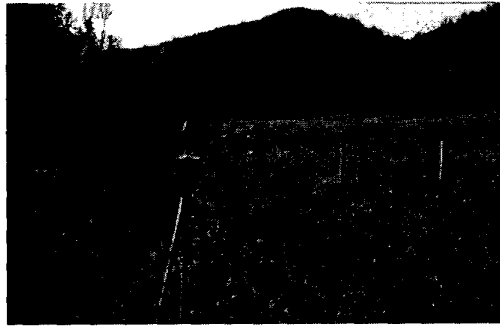
Figure 2. Overview of the Handheld Antenna Array Testbed (HAAT)

## 2.3 Data Processing

The data are processed with a computer using a multi-target least-squares constant modulus algorithm (MT LSCMA). This beamforming algorithm uses a direct matrix inversion to calculate element weights for each block of 64 to 320 samples. The reference signal for the matrix inversion is obtained by normalizing the complex beamformer output to a constant magnitude. The algorithm adaptively calculates and updates two weight vectors, one to optimize reception of each signal. Two iterations of the algorithm are run on each block, and each updated weight vector is applied to the data used to calculate that weight vector. A hard orthogonalization is performed for each block so the two weight vectors do not converge to the same solution. One weight vector captures the desired signal and the other captures the interfering signal, but sometimes the desired signal switches from one MT LSCMA beamformer output to the other. While *a priori* knowledge of the signals is not used in the beamforming, the two output signals are interchanged as necessary, using the signal frequency as a criterion, to keep the signal from a given transmitter on the same output port throughout each measurement.

The processing software calculates signal-to-interference-plus-noise ratio (SINR) and signal-to-noise ratio (SNR) before and after beamforming for each signal and for each channel. An FFT is performed on each block of data samples. Signal power in 100 Hz bandwidth about each of the two received baseband signals (near 4 and 5 kHz

respectively) and noise power in 100 Hz centered on 7 kHz are measured. The improvement in SINR at a given cumulative probability level after beamforming is denoted by  $\Delta$ SINR. The theoretical mean output SINR of an ideal maximal-ratio diversity combiner in the absence of interference provides an upper bound estimate of the mean SINR after beamforming in the presence of interference. This estimate is calculated by summing the mean SINRs of the four channels.

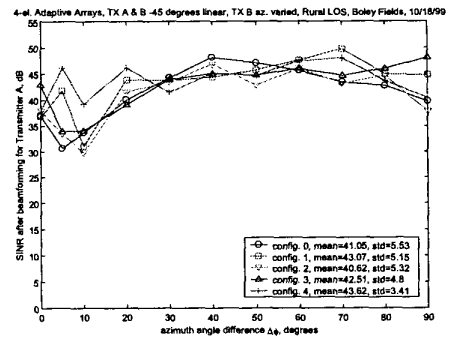


**Figure 3.** Rural Line-of-Sight Channel (Boley Fields in the Jefferson National Forest): view with transmitters in foreground, looking toward receiver.

## 2.4 Experimental Results

A typical experimental scenario is shown in Fig. 3. This site is classified as rural, line-of-sight. The controlled experiments with a receiver that was stationary or moving at a uniform speed on a linear positioner showed that mean SINR for the desired signal could be improved from about 0 dB before beamforming to 30 to 50 dB after MT-LSCMA beamforming. Fig. 4 shows mean SINR results for measurements at the site in Fig. 3. In addition to the 30-50 dB improvement in mean SINR, similar improvements in SINR were seen at cumulative probabilities of 0.1% to 10%. SINR of 25-40 dB was measured in urban and suburban line-of-sight and non line-of-sight peer-to-peer scenarios. In multipath channels, these performance levels were achieved even when there was no separation between the transmitters in azimuth angle as seen from the receiver, and no difference in the orientations of the two transmitting antennas. For the experiments in which the receiver was hand-carried at walking speeds, the mean SINR improvement in the outdoor suburban line-of-sight peer-to-peer scenario was approximately 37-41 dB, and the mean SINR after beamforming was 21-27 dB in the suburban, mostly non line-of-sight microcell

scenario. The lower SINR in the microcell scenario is partly due to the low SNR caused by attenuation of the signal over the longer propagation path. In the multipath channels measured, a dual- or multi-polarized antenna array generally provides no more than a 3 dB advantage over a co-polarized array, indicating that in these channels polarization flexibility can be helpful but is not critical.



**Figure 4.** Results of interference rejection measurements in rural line-of-sight environment shown in Fig. 3: mean SINR after adaptive beamforming plotted as a function of azimuth angle separation between transmitters

## Acknowledgements

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