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EXPERIMENTAL RESULTS FOR AN SDMA MOBILE COMMUNICATIONS ANTENNA ARRAY SYSTEM

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ABSTRACT

This paper presents experimental results for a Spatial Division Multiple Access cellular mobile communications system. The basestation antenna array testbed used to obtain the results is described in addition to sophisticated signal processing algorithms applied to the received data. These algorithms perform source tracking, beamforming for noise and interference reduction, and data detection. Simple experiments involving multiple co-channel users have been performed and results are presented in terms of output bit error rate. These results show that SDMA may be a technically feasible way to increase the spectrum efficiency of cellular mobile communications networks.

1. INTRODUCTION AND BACKGROUND

The use of spatial diversity in wireless communications has recently received considerable attention [1]-[7]. Specifically, basestation antenna arrays combined with adaptive beamforming techniques offer the possibility of increased channel capacity, wider area coverage, as well as mitigation of fading effects. The general goal in so-called Spatial Division Multiple Access (SDMA) based systems is that of exploiting the spatial dimension (i.e., the fact that co-channel users are located at different points in space) to separate co-channel users.

Inherent to SDMA techniques is the need to characterize the *spatial* channel formed between the each mobile user and the basestation antenna elements for the uplink (and vice versa for the downlink). In complicated multipath scenarios (as found in urban and indoor environments), where there is no simple parameterization of the spatial channel, channel identification is performed via estimation of the cross correlation of received data and a known user training sequence (i.e., a temporal reference) of limited duration. Then, the minimum mean squared error (MMSE) Wiener solution, can be implemented [1]-[2]. This approach, known as optimal combining, exploits the complex multipath fading present in the scenario. Another approach is that of least squared error (LSE) estimate based on the pseudoinverse of the matrix of the user's spatial channels [8]. This method, in effect, spatial decorrelates the incoming signals. The resulting user waveform estimates are applied to a data detection routine to estimate the transmitted symbols.

On the other hand, other scenarios are such that the spatial channel often admits a simple parameterization. Such is the case in rural environments where a simple parameterization in azimuth angle is possible. Here, the channel estimation problem is one of direction-of-arrival (DOA) estimation. Well known approaches such as the periodogram or the high resolution MUltiple SIgnal Classification (MUSIC) DOA estimators can be applied for this purpose [9]. Once the user DOA's have been estimated, the MMSE or LSE approach can be applied for user waveform estimation and subsequent data detection.

While several theoretical studies of SDMA systems have already been conducted [3],[5], relatively few experimental results have been reported (an exception includes [6]). This paper describes results of tests conducted in the context of the RACE II Project R2018–Technology in Smart Antennas for UNiversral Advancec Mobile Infrastructure (TSUNAMI) using a hardware array of antenna elements in addition to sophisticated parameter estimation/tracking and adaptive beamforming techniques for scenarios involving multiple co-

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channel users transmitting DECT-type signals. System performance is represented in terms of bit error rate (BER). The results show that an SDMA approach may be a technically realizable manner in which to increase user capacity.

The remainder of the paper is organized as follows: First Section 2 briefly describes the hardware testbed. Then Section 3 presents the signal processing algorithms which have been implemented. Section 4 testbed results are discussed and lastly, Section 5 offers some concluding remarks as well as directions for future work.

2. HARDWARE TESTBED

The antenna array consists of eight 1.89GHz dual polarized patch resonator elements uniformly spaced along a line with half-wavelength inter-element spacing. Each antenna is equipped with a calibration coupler for equalization of the receivers' transmission factors. Each receiver is comprised of a pre-selection filter, a low noise amplifier and a mixer. For the up-link, down-conversion was accomplished in two stages: from 1.89GHz to an IF frequency of 110MHz, then quadrature down-conversion to baseband. (For the down-link, eight quadrature up-convertors and linearized power amplifiers shift the base-band signal up to 1.89GHz.) The IF section uses a digitally controlled automatic gain control, a selection filter and two mixers for I/Q down-conversion. A digitized versions of the resulting analog signals are obtained via eight bit ADC's at a rate of three samples per symbol. Two digital beamforming and demodulation TMS320C40 DSP processor based cards perform the signal processing tasks (i.e., source tracking, beamforming, and demodulation). These have access to a 16MB DRAM card for data storage during the experiments. The output of the beamformer is applied to a DECT baseband processor which controls DECT system timing. The DECT protocol for link establishment and transmission from DECT mobiles is handled by a microprocessor allowing data collection from the mobile alongside the adaptive antenna data. Configuration of the testbed, running of the experiments as well as storage of results is accomplished by a single PC. A standard DECT reference antenna is available also. Two DECT mobiles are used in the experiments.

3. SIGNAL PROCESSING ALGORITHMS

An algorithmic block diagram of the system is shown in Fig. 1. A sequence of L snapshot vectors $\{\mathbf{y}(k)\}_k^{k+L-1}$ are applied to the MUSIC algorithm, the DOA estimates of which are refined by a bank of scalar Kalman

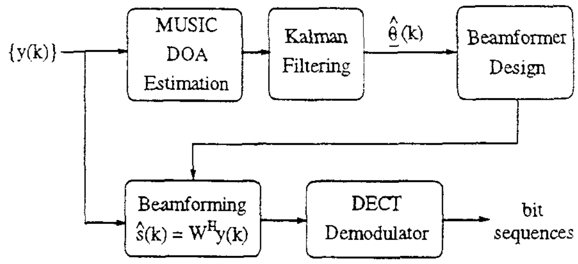

Figure 1: Algorithmic Block Diagram of System

filters [9] yielding the estimated source DOA vector $\hat{\underline{\theta}}$. These, in turn, are used in the design of simple interference nulling type beamformers (whose columns form a matrix $\mathbf{W}$) designed via a Gram-Schmidt orthogonalization of the associated steering vectors. The signal estimates at the output of the beamforming matrix, $\hat{\mathbf{s}}(k)$ are applied to the DECT demodulator to yield the estimated output bit sequences as shown in Fig. 2.

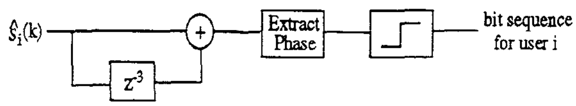

Figure 2: Demodulator Structure

4. RESULTS

The (uplink) scenario considered is described in Fig. 3. Two moving co-channel users simultaneously transmit

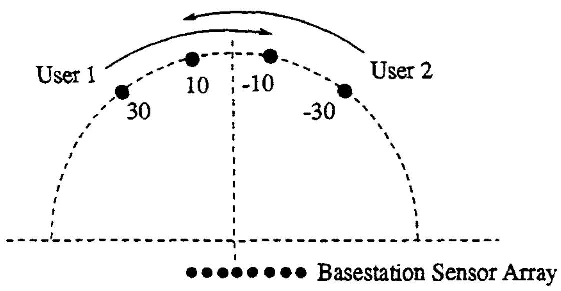

Figure 3: Test Scenario

DECT signals to the basestation for a period of approximately 30 seconds. The test scenario would correspond to a rural environment wherein the spatial channel is well modeled by a single parameter (i.e., azimuth). The users cross in angle at approximately 0° (array broadside) at $t =\sim$ 17sec.

The output of the MUSIC-Kalman Filter based DOA tracker is shown in Fig. 4. The DOA estimates are seen to roughly correspond to the movement of the mobiles. Note, however, that there is a loss of "data association" [9] when the sources cross in angle. That is, each element of the final DOA output estimation vector is not associated with one and only one source for the duration of the track. In practice, this problem has been solved by better control of the measurement noise of the Kalman filters.

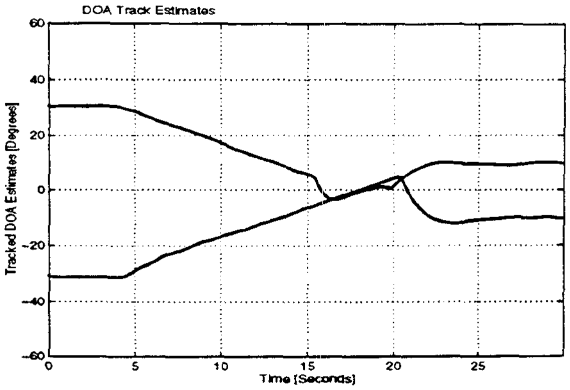

Figure 4: DOA Tracking

As indicated earlier, the DOA estimates are used to design the beamformers for each user. Figs. 5, 6, and 7 show the spatial magnitude response of the two beamformers at various points in the track. It is seen that the beamformer associated with each user places a null at the estimated DOA of the other user.

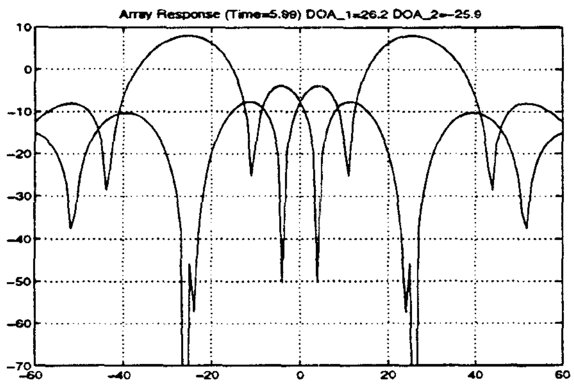

Figure 5: Beamformer Response

Lastly, Fig. 8 compares the bit error rate (BER) for user one at the output of the system shown in Fig. 1 compared against that obtained by directly attempting to demodulate the output of sensor four (i.e., no spatial filtering).

It is seen that the nulling capability of array is such that far better performance is offered by the system

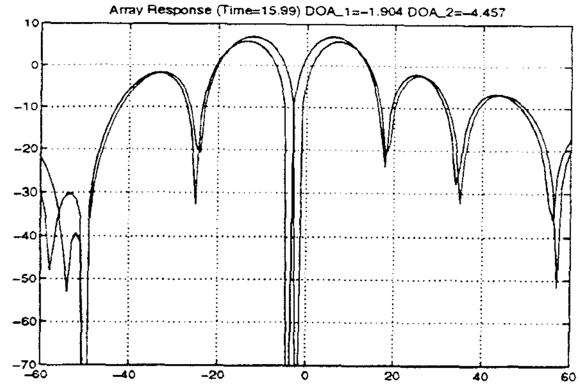

Figure 6: Beamformer Response

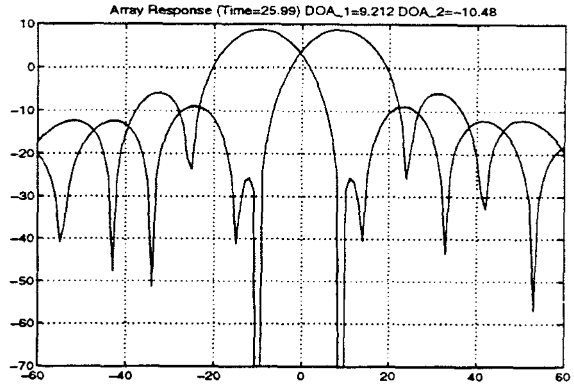

Figure 7: Beamformer Response

shown in Fig. 1 than the conventional single antenna system (except when the tho sources cross). In practice, the problem of crossing sources and the resulting increase in BER can be avoided by proper channel allocation procedures [3].

5. CONCLUSIONS AND FUTURE WORK

This paper has presented results from a mobile communications base station hardware testbed equipped with an array of antennas and DSP boards to carry out a variety of signal processing tasks. In particular: user tracking is achieved by a combination of the MUSIC algorithm and Kalman filtering, user separation is realized via a Gram-Schmidt spatial decorrelator, and data detection is provided by a simple delay-and-multiply type structure. Simple experimental results have indicated that SDMA may be an appropriate, technically realizable manner in which the capacity of cellular communications systems can be increased.

Several areas for future work remain. These include:

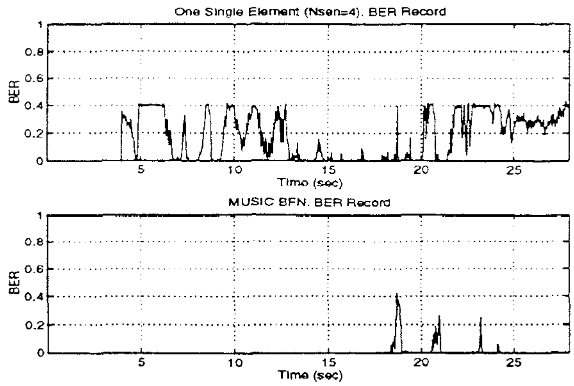

Figure 8: Array/Single Sensor BER Comparison

- *Downlink:* Firstly, it is of interest to implement experimental tests for the downlink. The principal problem here is that of downlink channel identification. In TDD the difference in time between uplink reception and downlink transmission at the base station may be such that the downlink channel cannot be approximated by that associated with the uplink. This is an even greater concern in Frequency Division Duplex (FDD) systems. When the users are well modeled as "slowly moving" point sources, the DOA parameters derived using uplink data can be used in the design of downlink transmit beamformers as in [6]. More detailed performance studies again in terms of BER are necessary. (Downlink results from the experiments are available on CD-ROM.)

- *Frequency Planning Options:* Also, as explained in [3], [10], capacity can be increased by "Same Cell Frequency Use" (i.e., SDMA) or "Reduced Cluster Size" wherein co-channel users are located in near-by cells. It is of interest to consider these options in a hardware implementation.

- *Non-Point Source Modeling:* Additionally, in some cases, the point source model used in the work described in this paper is not appropriate. A decade ago experimental studies reported in [11] indicated that local scattering effects in are such that the spatial channel may be more accurately modeled by a spatially Gaussian distributed source. This model has been used in downlink studies (via theory and simulation) reported in [3], [10]. Experimental work confirming the conclusions obtained in these studies is necessary.

These issues will be dealt with in TSUNAMI II [12].

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