ON THE MULTICHANNEL CHARACTERISTICS OF A 1.8 GHZ SMART ANTENNA SYSTEM USING A CIRCULAR ARRAY IN REALISTIC NON-STATIONARY WIRELESS SCENARIOS*

Weidong Yang, Adnan Kavak, and Guanghan Xu

Department of Electrical and Computer Engineering, The University of Texas, Austin, TX 78712-1084, USA

ABSTRACT

In mobile communications, smart antenna systems that utilize an antenna array and perform advanced signal processing techniques can achieve greater channel capacity and improve link quality by selective reception/transmission at the base station. However, development of adaptive signal processing algorithms for smart antenna system applications require the accurate knowledge about the multichannel propagation characteristics. A few experimental results on the spatial signature variation of a uniform linear array (ULA) at 900 MHz have been reported. This paper presents the experimental results on the channel propagation characteristic variations of a 1.8 GHz smart antenna system using a uniform circular array (UCA) in moving mobile scenarios. The results indicate that the stability of direction-of-arrivals (DOAs) of multipath components in all scenarios, and the unstability of the spatial signatures in scenarios with strong multipaths.

1. BACKGROUND

The rapid increase in the number of users of cellular phones and personal communication devices poses certain challenges for mobile communications, such as limited frequency spectrum and co-channel interference. With an antenna array and proper array signal processing techniques, a *smart antenna system* [1, 5] can alleviate these problems by suppressing the interference and reducing the effect of multipath fading. However, the successful applications of many existing array signal processing techniques with smart antenna systems require the knowledge about the channel propagation characteristics between a mobile terminal and an antenna array. As spatial signature (SS) captures much of the channel propagation characteristics, and they are used for selective transmission/receiving techniques, when we talk about channel propagation characteristics, we will mainly concern ourselves with spatial signatures. As the location of a mobile terminal can change at different rates, depending on the speed at which the mobile terminal is moving, the channel propagation characteristics can change at different rates also. It has been proved that when the terminals are stationary [3], their spatial signatures (SS) change little over a long time (8 hours). Also when the mobile terminal displacement between two signal snapshot intervals is small enough, the spatial signatures do not change much. These results have proved the feasibility to use spatial-signature-based selective downlink transmission techniques for Time-Division-Duplex (TDD) schemes in which uplink and downlink share the same carrier frequency. The results also implied that direction-of-arrival (DOA) based selective downlink transmission techniques can be used for Frequency-division-Duplex (FDD) schemes. However, the applicability of the above techniques is not clear for non-stationary wireless environments, where the movement of the mobile terminal or its surrounding can substantially change its spatial signature over a short period of time. Hence there is still a need to study and to understand the effect of non-stationary scenarios on multichannel propagation characteristics of antenna arrays. Therefore, we conducted extensive experiments in some suburban environments. In the following, we shall present our experimental results pertaining to the variation of spatial signatures, which, in turn, involve the direction-of-arrivals (DOAs) of multipaths, and their relative strengths and phases.

*THIS WORK WAS SPONSORED IN PART BY AN NSF CAREER AWARD UNDER GRANT MIP-9502695, TEXAS ADVANCED RESEARCH PROGRAM, THE OFFICE OF NAVAL RESEARCH UNDER GRANT N00014-95-1-0638, THE JOINT SERVICES ELECTRONICS PROGRAM UNDER CONTRACT F49620-95-C-0045, SOUTHWESTERN BELL TECHNOLOGY RESOURCES, INC., TI RAYTHEON, EQUIPMENT DONATION FROM INTEL. THE UNITED STATES GOVERNMENT IS AUTHORIZED TO REPRODUCE AND DISTRIBUTE REPRINTS FOR GOVERNMENTAL PURPOSES NOTWITHSTANDING ANY COPYRIGHT NOTATION HEREON.

2. EXPERIMENT SETUP

The base station used in the experiments is a smart antenna testbed developed by the wireless communication group of Univ. of Texas at Austin. At the base station, a 7-element antenna array was arranged in a circular fashion with a radius about 10 cm., and the 8th antenna was mounted on a branch about 30 cm. away from the circular array's center. The 8-element antenna array was placed at the top of a 20 meter steel tower. The antenna elements were connected with cables to a smart antenna testbed, which sampled signals at 3.072 MHz. The data samples were recorded in the PC which controlled the testbed. A dipole antenna driven by a HP 8662A synthesizer in a car was used as the mobile terminal. The carrier frequency was around 1880 MHz. To better understand the variations of spatial signatures with large displacements, as a first step, we studied the change of spatial signatures of the mobile terminal within a displacement of 2λ. The dipole antenna, attached to a wood-stand of a height about 1.75m, was moved along a linear line for 2λ, with a uniform step of 0.2λ. At each position the signal snapshots with about 10,000 samples from each element of the antenna array were collected. Hence we can estimate the spatial signature(a 8×1 vector) of the mobile terminal from a large data matrix. Within the displacement of 2λ, we estimated the spatial signature of the mobile terminal for 11 times.

We conducted many experiments within the J.J. Pickle Research Campus of The University of Texas at Austin. In that environment, there were no highrises and not too many buildings and physical structures. It could be considered as a suburban area. In this paper, we will present the results in two scenarios: a) There was a line-of-sight between the mobile terminal and base station, and was a local scattering building (LOSWLS scenario), b) there was no line-of-sight between them (NOLOS scenario).

3. EXPERIMENTAL RESULTS

When the mobile terminal is moving within a short distance, from Figure 1 and Figure 2, one can have a rough idea about the propagation characteristics of the environments. The spatial signatures are highly correlated (0.9) and there is almost no diversity gain in LOSWLS scenario (Figure 1). On the contrary, in NOLOS scenario the spatial signature correlation decreases up to 0.5 and there is some diversity gain. These two figures imply that in NOLOS scenario spatial signatures span relatively a large angle range and there must be significant variation in SS angles.

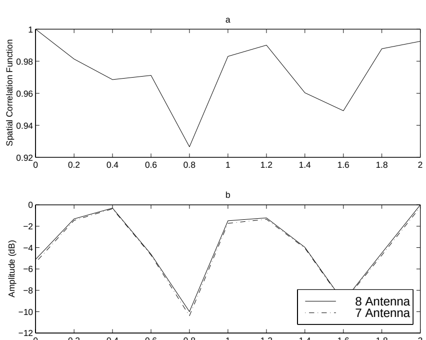

Figure 1. LOSWLS Moving MT Scenario: (a) Spatial Correlation Between the Current SS and 1st SS, (b) Diversity Comparison

The DOA estimates obtained via classical beamforming [4] and subspace smoothing approach [6, 2] are shown in Figure 3 and Figure 4 for LOSWLS and NOLOS scenarios respectively. They change little within 2λ displacement of the mobile terminal. It is found that two path model is enough to represent spatial signatures.

Figure 5 and Figure 7 show the variation of path amplitudes and relative multipath phases for LOSWLS and NOLOS cases respectively. In LOSWLS scenario (Figure 5), there is approximately 13dB difference in amplitudes between the two paths and multipath phase changes up to 40° in relative to the direct path. However, in NOLOS scenario (Figure 7) amplitudes of the two paths are approximately the same and relative multipath phase attains 100°.

Thus, based on the these characteristics, spatial signature variation can be explained geometrically by Figures 6 and 8: **In LOSWLS scenario**, there is a small angle spread, i.e., $\theta_1 \approx \theta_2$, and then

$$a_i \approx a(\theta_1)[1 + \beta_i].$$

The spatial signature vectors a_1 and a_2 will point approximately to the same direction but their amplitudes are expected to fluctuate within 2λ. Spatial signature variation as shown in Figure 9 justifies the above characterization. There is approximately 30 percent (17°) angle change, and this implies small angle spread, but there is a significant change in the spatial signature amplitude which reaches maximum 5dB in relative to the first spatial signature and 8dB in relative to the last spatial signature. Hence, the spatial signature undergoes *fast non space selective fading.* **In NOLOS scenario**, the above observations, however, are opposite. There is a large angle spread and

$$a_i = a(\theta_1) + \beta_i a(\theta_2).$$

The path vectors will span the full space and therefore spatial signature does not exhibit any preferred direction and the changes will be in both amplitude and the direction. As shown in Figure 10, angle change reaches 100 percent in which the spatial signatures are almost orthogonal and the amplitude change is around 2dB. In this case the spatial signature undergoes *fast space selective fading.*

4. CONCLUSION

In this paper, the vector channel propagation effects of a mobile terminal movement within short distance (2λ) on the multichannel propagation characteristics of a smart antenna system are explored for realistic LOSWLS and NOLOS wireless scenarios in a suburban environment. Experimental results and their analyses on the variation of spatial signatures, DOAs, and complex path fading parameters are presented. In both scenarios, DOAs remain almost unchanged and the spatial signatures can change primarily due to complex path fading. In LOSWLS scenario, spatial signatures vary significantly in amplitude but moderately in angle even with the 2λ movement of mobile terminal. In NOLOS scenario, however, spatial signatures span the large angle range while their amplitudes do not change significantly. Hence, in non-stationary scenarios spatial signature based selective downlink transmission techniques may be difficult. Either better downlink transmission techniques need to be developed or downlink channel variation should be modelled and tackled accordingly in selective downlink transmission.

REFERENCES

[1] Millnert M. Viberg M. Anderson, S. and B. Wahlberg. An adaptive array for mobile communication systems. *IEEE trans. on Veh. Tech.*, pages 230–236, January 1991.

[2] S.S. Jeng, Okamoto G. Xu G. Lin, H.P., and W.J. Vogel. Multipath direction finding with subspace smoothing for wireless communications. In *International Conf. on Acoustics, Speech, and Signal Processing*, April 1997.

[3] Xu G. Lin H.P. Jeng, S. S. and W.J. Vogel. Experimential studies of spatial signature variation at 900 mhz for smart antenna systems. *IEEE trans. Ant. and Prop.*, pages 953–962, July 1998.

[4] H. Krim and M. Viberg. Two decades of array signal processing research. *IEEE Signal Processing Magazine*, pages 67–94, July 1996.

[5] J.H. Winters. Smart antenna for wireless communications. *IEEE personal Communications Magazine*, pages 23–27, February 1998.

[6] G. Xu and H. Liu. Effective transmission beamforming scheme for frequency-division-duplex digitial wireless communication systems. In *International Conf. on Acoustics, Speech, and Signal Processing*, May 1995.

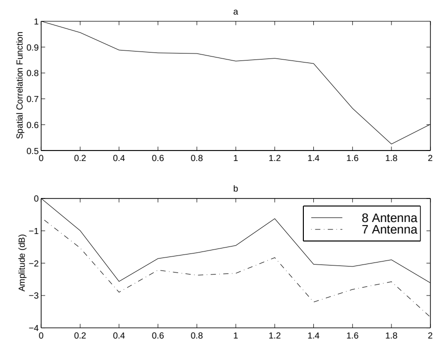

Figure 2. NOLOS Moving MT Scenario: (a) Spatial Correlation Between the Current SS and 1st SS, (b) Diversity Comparison

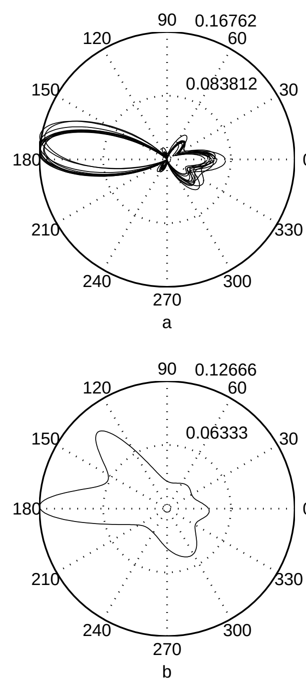

Figure 3. LOSWLS Scenario: DOA Estimates Via (a) Beamforming (b) Subspace Smoothing Approach

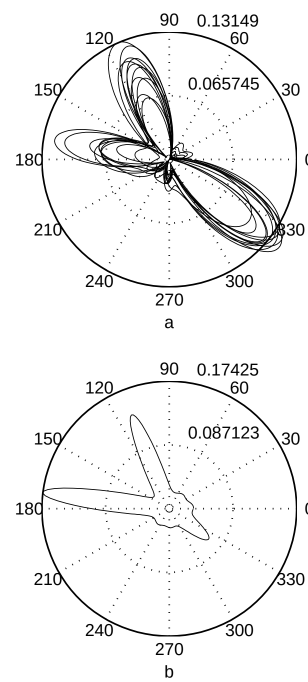

Figure 4. NOLOS Scenario: DOA Estimates Via (a) Beamforming (b) Subspace Smoothing Approach

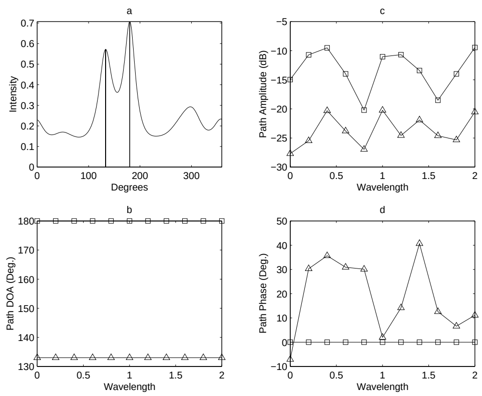

Figure 5. LOSWLS Scenario: (a) MUSIC Spectrum, (b) DOA Estimates, (c) Path Amplitudes, (d) Relative Multipath Phases

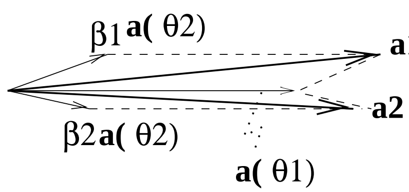

Figure 6. Illustration of SS Change in LOSWLS Scenario

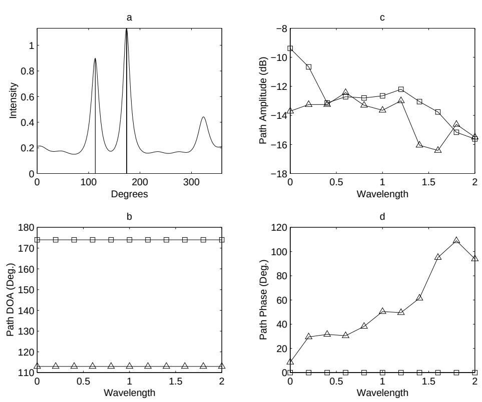

Figure 7. NOLOS Scenario: (a) MUSIC Spectrum, (b) DOA Estimates, (c) Path Amplitudes, (d) Relative Multipath Phases

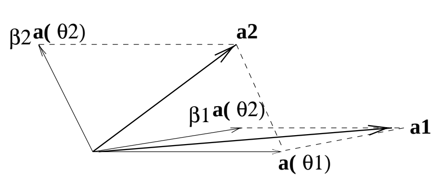

Figure 8. Illustration of SS Change in NOLOS Scenario

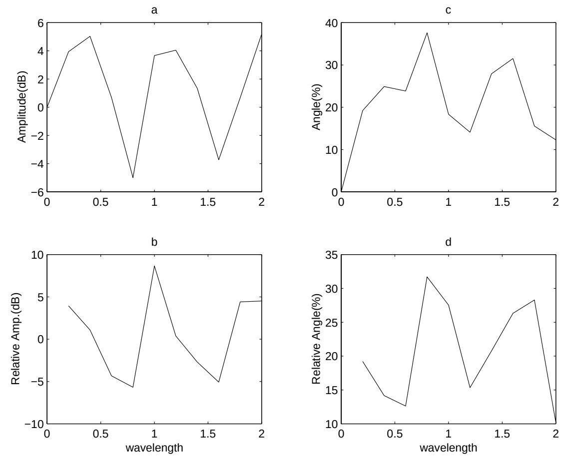

Figure 9. Spatial Signature Variation in LOSWLS Scenario: Amplitude Change of the Current SS in Relative to the (a) 1st SS (b) Last SS, Angle Change of the Current SS in Relative to the (c) 1st SS (d) Last SS

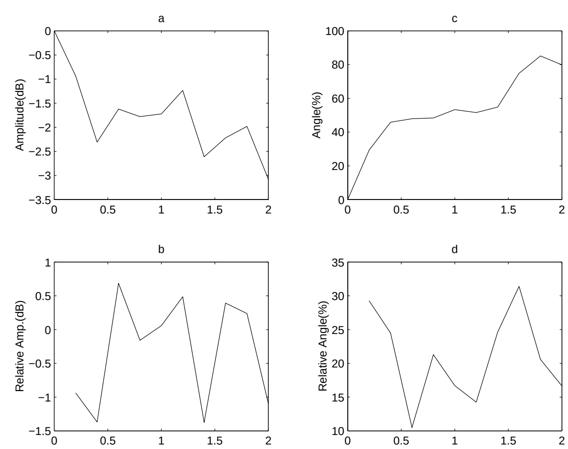

Figure 10. Spatial Signature Variation in NOLOS Scenario: Amplitude Change of the Current SS in Relative to the (a) 1st SS (b) Last SS, Angle Change of the Current SS in Relative to the (c) 1st SS (d) Last SS