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STUDIES OF INDOOR PROPAGATION CHARACTERISTICS OF A SMART ANTENNA SYSTEM AT WIRELESS COMMUNICATION

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ABSTRACT

The research is focused on determining the feasibility of smart transmit and receive handset antennas. The goals are to show reduced power consumption, improved capacity and better link reliability. Smart antenna systems are becoming practical for indoor applications such as wireless local area networks (LANs). However, the challenging indoor propagation environment is one of biggest obstacles for designing smart antenna wireless networks. In order to fully understand and characterize channel propagation characteristics or vector channels of smart antenna systems in indoor environments, experiments are conducted using a 1.8 GHz real-time smart antenna test bed with a uniform linear array. The effects of mobile user motion on the vector channel variation are studied in line-of-sight (LOS) and non-line-of-sight (NOLOS) indoor scenarios. The experimental results on the variation of vector channel parameters such as space-time correlation properties, spatial signatures, direction-of-arrivals (DOAs), multipath angle spread, and complex path fading are presented.

Key words: Indoor propagation, vector channel, smart antenna systems, space-time correlations

INTRODUCTION

The demand for wireless communication systems such as wireless local area networks, mobile cellular telephony, and radio paging has been greatly expanded. These wireless systems require state-of-the-art communication techniques to support many users at high data rates. Design and performance analysis of smart antenna systems require both the spatial and the temporal channel propagation information of the signals present at each antenna array element. Since a vector of signal samples is received/transmitted at each instant of time, the channel propagation characteristics between a mobile terminal (MT) and an antenna array is described by a vector propagation channel. For single antenna systems, it is acceptable to consider only scalar propagation channels that provide temporal information such as large-scale (path loss, diffraction) and small-scale (multipath fading, Doppler shift, delay spread) propagation effects.

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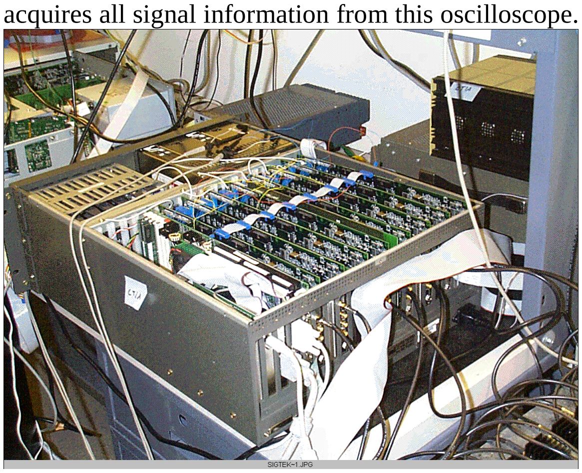
In addition to temporal channel propagation information, spatial information regarding the correlation of signals among multiple antennas, direction of arrivals (DOAs), and multipath angle spread is needed to fully characterize vector propagation channels of smart antenna systems. The variation of vector channel parameters depends on the type of the propagation environment (indoor, rural,

suburban, urban) and the radio link between the MT antenna and the BS antenna array. For instance, when the direct radio path is blocked, only multipath signal components propagate and the received signal experiences deep fade levels. Multipath signals arriving from different DOAs with almost equal strengths and opposite phases may add up constructively or even cancel out. With the emerging applications of smart antenna systems in indoor environments such as wireless local area networks (LANs), there is a great need to study and better understand the indoor vector propagation channel characteristics. Okamoto4 has recently proposed a smart wireless LAN (SWL) system which adapts smart antenna systems to wireless LANs.

Spatial aspects of indoor radio propagation were initially addressed in where data was collected with displacement around the receiver. In this paper, we study the variation of vector propagation channels at 1.8 GHz due to mobile user movement. The difference of this study from Jeng et al.10 is that measurements are taken at 1.8 GHz in both the LOS and the NOLOS scenarios of the hallway type indoor environment. We present the experimental results of our vector channel measurements regarding the space-time correlation behavior with both the spatial (spatial signature change, DOAs, multipath angle spread) and the temporal (complex path fading) properties of the indoor radio channel.

VectorImPulsEResponse Measurement System (VIPER)

A software-defined, wideband vector channel measurement receiver was developed. VIPER also supports transmit and receive diversity measurements. The VIPER receiver is capable of receiving signals up to 400 MHz in bandwidth and processing these signals in software. The receiver serves as a test bed for smart antenna algorithms and performs the function of a multipath measurement system for comparing antenna algorithm performance results in multiple radio channel environments. Figure below shows the photograph of the VIPER RF front-end section. A four-channel oscilloscope is used for the sampling system, and the computer acquires all signal information from this oscilloscope.



MAAT experimental

Overview of the experimental setup

Extensive measurements have been carried out with the developed hardware test beds. These measurements include diversity measurements at the handset, effect of antenna element spacing and operator tissue on diversity, adaptive beam forming, angle of arrival, verification of channel reciprocity, and wideband vector channel measurements .Sample diversity measurements for an outdoor non-line-of-sight channel. Note that correlation is well below 0.7, which is good for achieving improvement due to versity. Figure 6 shows diversity gain as a function of antenna spacing.

There is about 9 dB of gain for 99% reliability and about 5-dB gain for 90% reliability almost independent of spacing down to 0.1 wavelengths. Extensive investigation was performed on adaptive beam forming using handheld antenna arrays. The investigation used small four element antenna arrays that were mounted on a receiver that could be carried like a mobile phone. The adaptive beam forming investigation consisted of over 250 experiments in rural, suburban, and urban channels with two mutually interfering transmitters. Controlled experiments provided a performance improvement of 25 to 50dB with a least-squares constant modulus algorithm (LSCMA). 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. Additional measurements were performed in which the receiver was hand-carried at walking speeds in peer-to-peer and microcell scenarios. The mean SINR improvement in the peer-to-peer scenario was approximately 37-41 dB, and the mean SINR after beam forming was 21-27 dB in the 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 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. MAAT system was used to carry out angle of arrival measurements, adaptive interference cancellation algorithms for a spread spectrum system (low bandwidth), and multi-spectral vector channel measurements based on a frequency sweep over 10 MHz bandwidth. The multi-spectral measurements reveal the flat fading nature of an indoor channel and a frequency selective fading nature for an outdoor to indoor channel. The VIPER was used to initiate a series of wideband vector channel measurements for a variety of channels (indoor, outdoor, etc.) with a bandwidth commensurate with IMT-2000bandwidth. Initial experiments were performed in an indoor environment.

Transmit diversity research

This section describes Virginia Tech's recent activities on transmit diversity at the handset. It involves investigation of the different aspects of this form of diversity. Transmit diversity is employed by

transmitting the symbol sequence over all the elements of an antenna array at the transmitter. The problem is de fined to maximize signal to noise (SNR) at the
receiver subject to constant transmit power. Different algorithms were proposed and techniques devised to implement transmit diversity at the handset for a flat fading channel. The techniques involve during a complex weight vector at the transmitter
to scale the symbols through different antenna elements. The proposed techniques were compared with respect to maximum achievable SNR and the convergence behavior. The techniques include early-late technique, subspace technique, gradient-based approach, and least square(LS) technique. The techniques were tested through simulations and results showed that the LS technique provided the most promising solution for a flat fading channel. Simulations indicate that 2-6 dB of performance gain for a 2-element array, and 5-12 dB of performance gain for a 4-element array compared to a single antenna system is possible for indoor environments. Feedback and latency issues associated with these proposed algorithms were studied. Simulations show that a coarse magnitude and phase quantization of the complex weight vector is possible with only slight performance degradation. The suitability of these algorithms with respect to their implementation in WCDMA standard of IMT-2000 was also studied. The channel structures and the signal format of WCDMA can accommodate the algorithms.

Transmit diversity demonstration

The feasibility of the transmit diversity system was demonstrated by a hardware
implementation. The setup consisted of a 2-element wideband transmit diversity test bed and VIPER as the receiver. The gain of one element was held constant while the phase of the other element was varied in discrete steps. Signal strength was measured for each phase setting and the setting providing the maximum power was identified and relayed back to the transmitter. Signal strength measurements were also done for individual antenna elements and performance of the diversity system was compared to those of single antenna system.

CONCLUSIONS

This paper has described Virginia Tech's research on smart handset antennas. Different test beds have been developed and propagation experiments have been carried out with these test beds. Channel measurements indicate performance improvement of diversity system over single antenna system. Narrow band measurements indicate up to 40 dB of interference rejection can be obtained using adaptive beam forming techniques with a four element array. Similar gains should be possible for wideband systems using appropriate algorithms. Wideband diversity experiments are underway with the VIPER system. Transmit diversity has been investigated for a flat fading channel and different algorithms have been proposed and verified by simulation. Transmit diversity has been demonstrated with a wideband signal in an indoor environment. Building on our experience with VIPER, a wideband handheld antenna array test bed with continuous data collection capability can be rapidly developed to support experiments to evaluate the performance of adaptive beam forming at the handset with wideband signals. In this paper, we have studied the variation of channel propagation characteristics (vector channel parameters) of narrowband smart antenna systems with the mobile terminal movement in a hallway-type indoor propagation environment. Measurements of vector channel parameters are taken by using a 1.8 GHz real-time smart antenna
Test bed with a uniform linear array at the base station. The mobile transmitter was placed in the hallways in such locations that both the line-of-sight (LOS) and the non-line-sight (NOLOS) indoor scenarios could be studied. Experimental results on the variation of vector channel parameters are presented.

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