Research Activities of Antennas and Propagation for Wireless Personal Communications in Taiwan

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Abstract Recent research interests in the field of wireless personal communications have been moving to the third-generation cellular systems for higher quality and variable speed of transmission for multimedia information. Spatial and temporal signal processing based on an antenna array will become a breakthrough technique for the cellular systems. In order to design and analyze an antenna array, a radio propagation model should be modeled in both the space and time domains, while traditional communication theory represents it as a delay profile in the time domain. The spatial characteristics (i.e., the angular profile) are important as well as the temporal ones. In this paper research activities on smart (array) antenna signal processing, spatio-temporal radio channel modeling and antenna design in Taiwan are introduced.

I. Introduction

The development of efficient wireless transmission systems is a challenge for modern communication engineering toward the realization of universal personal communications, which will offer access to all kinds of information services at a reasonable cost at any place and time. Cellular and cordless telephones as well as wireless data for wide or local area services can be consider as the first step in this direction. A profound knowledge of the radio channel characteristics is a prerequisite to achieve an optimum system design. Therefore, a world-wide research activities are focused on VHF (Very High Frequency) and UHF (Ultra High Frequency) bands, which provide most need of the aforementioned services, to examine the variations of the channel in space, time, and polarization separately.

In this paper, research activities of both smart antenna signal processing and antenna design in Taiwan will also be introduced. Research topics of the latter one include space-time (ST) beamforming and 2-D RAKE receivers for CDMA and non-CDMA systems, respectively. Developing effective Algorithms to suppress interference is the main goal, which can increase the capacity of cellular systems. To achieve optimized algorithms, characterization of vector radio channels is necessary. The research subjects of antenna design are mostly emphasized on planar-type antennas such as microstrip, slot, and chip antennas.

II. Radio Channel Characterization

A. Indoor radio channel

In Taiwan, National Science Council has sponsored some independent researches on modeling of radio propagation into and within buildings for the applications of WLAN and WLL (wireless local loop). Tarng and et. al., has developed a three-dimensional (3-D) site-specific and an effective models to analyze vector field and to calculate radio coverage, respectively [1]. Figure 1 illustrates the measured and calculated path losses of 2.44-GHz radio propagation along a hallway of an office building. Several models are employed and 3D-patched model yields the best accuracy with minimized standard deviation of error.

In [2], a novel model combining a 2-D site-specific model and a statistical model is developed to characterize the small-scale fading and estimate space diversity in office buildings. In addition to accurately predicting average field strength, the model can quantify the relative mean contribution of diffused scattering in an indoor environment with a factor r. It is found that the factor is within a narrow range when the field intensity fluctuation is in or close to saturation regions.

Mechanism of radio propagation into building had also been studied. It is found that (1) the direct transmitted wave is the dominant mode in some situations; (2) the path loss neither increases nor decreases monotonically as a function of increasing floor level; (3) the dominant propagation modes vary as the number of separation floor level changes [3].

B. Spatio - temporal channel simulation tool

A software package is developed to investigate spatio-temporal characteristic of radio multipath channel. It can estimate the field, angle of arrival (AOA), polarization and delay time of each path with a site-specific propagation model (ray-tracing based). Our tool combines the physical propagation model, digital map database, and graphical user interface to illustrate the spatial signature of radio propagation in a macrocellular environment. One of the examples for 1.7-GHz radio propagation at the campus of National Chiao-Tung University in Hsin-Chu, Taiwan is illustrated in Fig. 2. Figure 2 illustrates the top view of the received ray paths in the physical environment. These received paths are found with the ray-tracing method, while the receiving antenna is situated at the top of a building with a height of 38.5m and the transmitting antenna is 1.6m above ground. The tool can determine the AOA of each received path and the rms of AOA spread is calculated and equal to 8.41O.

III. Smart Antenna Signal Processing

Research topics on smart antenna signal processing include space-time (ST) beamforming and 2-D RAKE receivers for non-CDMA and CDMA systems, respectively. The major efforts are put in the development of effective algorithms for interference suppression. An ST beamformer performs linear combining on the spatio-temporal data obtained by oversampling the baseband data received by an antenna array. By oversampling, a larger data dimension can be obtained for signal enhancement and interference suppression. Either the coherent (maximum ratio) or optimum (MMSE) combining criterion can be employed to determined the beamforming weight vector. Here we present an ST beamformer for sectored wireless communications. The beamformer is designed to effectively collect multipath signals from an angular sector in space, and suppress strong out-of-sector interference. It is blind in that no training sequence is needed for channel estimation. Figure 3 shows the output SINR performance of the ST beamformer using a 12-element array and an oversampling rate of 2. Clearly, the ST beamformer significantly outperforms the conventional space-only beamformer in the presence of rich interference.

The 2-D RAKE receiver is essentially a spatio-temporal extension to the conventional time-only (1-D) RAKE receiver with an antenna array employed to exploit the spatial degree of freedom, and a certain smartness incorporated for combating multi-access interference. Again, either the coherent or optimum combining criterion can be employed to determine the RAKE weight vector. Here a blind adaptive beamspace-time (BT) RAKE receiver is presented for sectored wireless CDMA communications. The receiver is designed in accordance with the following procedure. First, a set of ST diversity processors is constructed to collect the multipath signals from a given spatio-temporal region, and to suppress unwanted MAI. Second, the outputs of these processors corresponding to different look directions and delays are coherently combined to fully utilize the multipath energy.
Figure 4 shows the capacity performance of the BT RAKE receiver using a 9-element array and 4-finger matched filter. Here MST, CST, MBT, and CBT denote optimum ST, coherent ST, optimum BT and coherent BT receivers, respectively. The proposed BT RAKE receiver is comparable to the optimum receivers, and significantly outperforms the coherent receivers in the presence of rich MAI.

IV. Antenna Design

Considering the needs of mobility and technology convergence, antenna design must consider the aspects of downsizing, multi- or wide-band, and/or multi-mode. Various multi-frequency/wide-band antennas have been studied by Wong and the co-workers [4]. The design goal was fulfilled by cutting a slot of suitable length and shape on the patch of a microstrip antenna. The slot partially divided the patch into an inner patch and an outer ring. The size of the inner patch mainly determined the higher frequency of the antenna, while that of the whole patch decided the lower one. Besides the studies of multi-frequency planar antennas, they have also worked on the design of patch antennas on cylindrical surface. By using the leaky mode of a microstrip line, Lin has developed a leaky-wave antenna for high-gain and frequency-scanning purpose [5]. To increase the antenna efficiency, several feed techniques were designed to avoid the excitation of the dominant non-radiating mode of the microstrip line.

Recently, Chung has proposed a two-port aperture-coupled microstrip antenna as shown in Fig. 5 [6]. The antenna was based on the structure of a traditional aperture-coupled microstrip antenna, but with an extra aperture on the ground plane for coupling a fraction of antenna power to another microstrip line (the second port) on the circuit substrate. By changing the position and size of the second aperture, the coupling power could be varied in a large range. Using this configuration, an Xband feedback-type antenna oscillator was established by serially connecting the antenna and an FET amplifier into a close loop [6]. The antenna in this design functioned not only as a radiator but also a feedback resonator. This feedback antenna oscillator concept has been extended to form a new spatially combining active antenna array. The active array contained four serially connected antenna-amplifier pairs, with an overall loop gain larger than 0 dB and a loop phase delay equal to a multiple of 360 degrees. For a more versatile use, a three-port slot antenna as shown in the inset of Fig. 6 has also been proposed [7]. This structure was a modification of a Wilkinson power divider. The series-loaded slot antenna played the role of the isolation lumped resistor. By changing the feed position of the offset-fed slot antenna, the equivalent impedance could be adjusted to the required one. The measured scattering parameters depicted in Fig. 6 demonstrated the good performance of the structure. Note that port 1 and port 2 are isolated to each other, so are port 3 and the remote radiation port. Furthermore, as the field is received from the antenna, the power is equally split to ports 1 and 2 but with 180-degree phase difference. A microstrip antenna version of this modified Wilkinson power divider has also been designed and showed good characteristics. Various circuits using this configuration have been demonstrated, including a dual circularly polarized antenna, an active transmitting antenna, and a balanced mixer integrated with antenna.

Planar Van Atta retrodirective array reflector, which possesses the advantage that the field reradiated by the reflector has a maximum in the direction of the incident plane wave, has also been extensively studied for possible applications in the intelligent transportation systems (ITS). The reflector contained several planar antenna pairs linked by planar transmission lines. The paired antennas were located symmetrically with respect to the reflector center and the electrical length differences among the connecting transmission lines were designed to be multiples of 360 degrees. Many active/passive retrodirective reflectors at different frequencies, using different antennas, and with retrodirectivity in E-plane and/or H-plane were implemented.

V. Summary

In Taiwan, many efforts have been put on the development of smart antenna systems for future wireless communication systems now or in the near future. The research subjects include analysis and design of antenna arrays, performance evaluation of adaptive array processing technique, design of a learning-based digital beamformer, and study of incorporating smart antenna into W-CDMA radio systems. These activities, however, future radio systems such as smart antenna or WLAN will increasingly require knowledge of the joint behavior of channels with respect to there variables to optimize their performance, particularly to support large numbers of users with high data rates.

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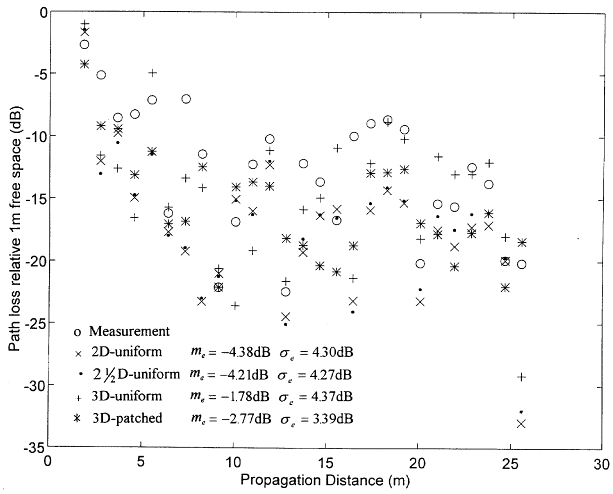

Fig. 1 The measured and predicted path losses of 2.44-GHz radio wave as a function of propagation distance. The transmitting and receiving antennas are both vertically polarized.

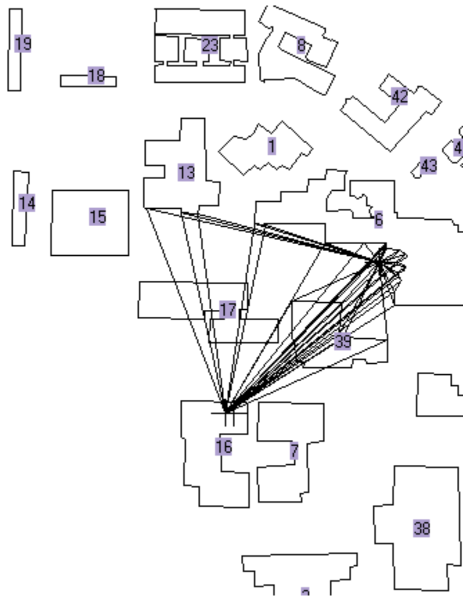

Fig. 2 Top view of building blocks at the NCTU campus and traces of the received paths

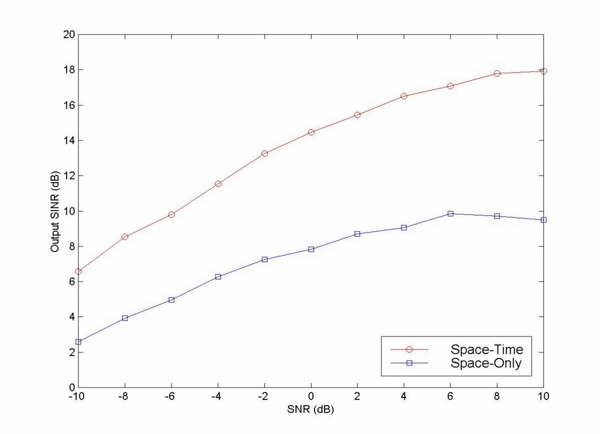

Fig. 3 Beamformer output SINR versus input SNR. There is one BPSK signal and eight BPSK interferers. SIR = -20 dB.

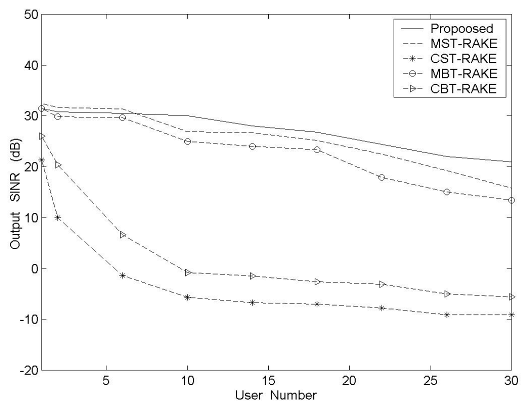

Fig. 4 RAKE receiver output SINR versus user number. The CDMA signals are spold codes. SNR = 0 dB.

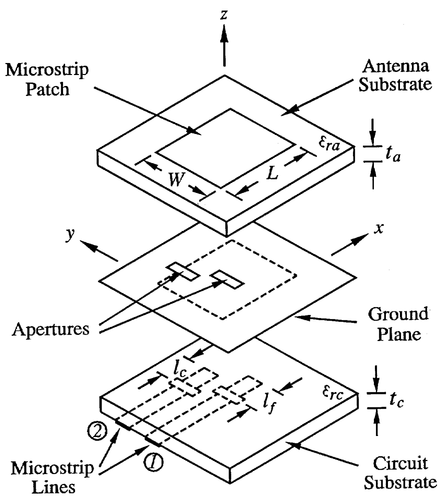

Fig. 5 Geometry of two-port aperture-coupled microstrip antenna

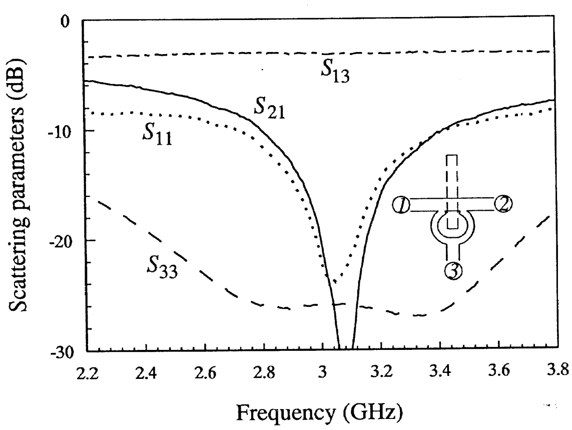

Fig. 6 Frequency response of a modified equal-split Wikinson power divider with an offset-fed slot antenna in place of the lumped resistor