

SPACE-TIME PROCESSING TDMA WIRELESS TESTBED

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ABSTRACT

The paper describes the architecture of the Stanford University (SU) TDMA standalone testbed. The testbed was developed to evaluate space-time processing (STP) algorithms for diversity, co-channel interference (CCI) and intersymbol interference (ISI) mitigation, array gain and space-time coding. It operates in both uplink and downlink modes and uses a hybrid (combining a real and simulated) channel environment. A description of transmit and receive schemes implemented on the testbed is presented.

1. INTRODUCTION

A testbed is useful to demonstrate the feasibility of STP transmit and receive algorithms in realistic wireless environment. It helps the system designer study trade-offs in performance gain, implementation complexity, and robustness of algorithms. It enables comparison of different algorithms in terms of CCI and ISI mitigation, coding, diversity, and array gain performance, in different channel scenarios. It provides insight into the practical issues of implementing algorithms and enables the researcher to come up with improved solutions.

Many testbeds have been built in the past for temporal and spatial characterization of channel and for performance evaluation of STP algorithms. The TSUNAMI II Stand-alone testbed [5] operates in uplink mode and uses an 8 antenna base-station receiver and 2 mobile units for transmitting modified GSM multiframe TDMA bursts. Various algorithms were tested on a real channel. The RACE Real Time Testbed (RTTB) [4] uses a 2 base-station and 2 mobile unit system, with a wide-band channel simulator for performance evaluation. The Ericsson GSM testbed evaluated adaptive antenna technology using a real, physical channel [1]. Lucent technologies and ATT Labs built a 4 element adaptive antenna array testbed to test uplink performance of 1.9 GHz IS-136 PCS base station [2]. The latter used an RF multipath fading simulator and demonstrated the importance of adaptive arrays in increasing the range and capacity of TDMA cellular systems. Lucent Technologies have built a real-time prototype to specifically demonstrate high capacity space-time architecture (V-BLAST) for rich-scattering wireless Channel [3].

In this paper we describe the SU STP testbed. The main objectives of the SU standalone testbed are:

- To provide a powerful, flexible, rapid prototyping system where different transmit and receive STP schemes can be tested with minimal hardware and software changes.

- To evaluate a full range of advanced and multi-purpose STP algorithms that provide co-channel interference (CCI) mitigation, inter-symbol interference (ISI) mitigation, transmit and receive diversity, space-time coding and array-gain in different channel conditions.

The testbed is unique since it uses a hybrid channel model which combines the benefits of a real channel and a full spectrum RF channel simulator. The channel simulator enables testing of algorithms on a wide variety of realistic channel conditions, which is difficult to obtain using a simple outdoor physical channel. Non-linearities and phase noise problems in transmit and receive antennas and RF components, sampling artifacts, frequency and phase offsets between transmit and receive clocks enable realistic testing of algorithms. The real channel provides scattering, reflection, refraction and diffraction effects prevalent in a natural environment. The testbed can operate in either uplink and downlink modes with minimal hardware changes. This added hardware and software flexibility to test different STP algorithms in a wide variety of channel conditions make the SU testbed valuable.

2. ARCHITECTURE

The SU testbed uses a single transmitter and a single receiver, with one or many co-channel interferers (CCI). The architecture is illustrated in Figure 1.

2.1. Transmitter

The transmitter consists of an signal generator, which is used to generate TDMA bursts from one of the following TDMA standards: GSM, NADC, PHS, DECT, PDC, and TETRA. It can be programmed to generate different data patterns with training sequence, both in continuous and burst frame format. The data is internally modulated to RF (902 MHz, -136 dBm to 20 dBm) and transmitted on a single RF output. As will be seen in section 4.1, this architecture is sufficient to test most transmitter schemes. Sophisticated STP coding algorithms, which involve coding data both in temporal and spatial domain and simultaneously transmitting data on multiple channel output, require further modifications. To test such algorithms, the HP generator is replaced with a PC controlled DSP board to generate coded digital data on as many as 4 outputs simultaneously. The data will then be externally modulated to RF.

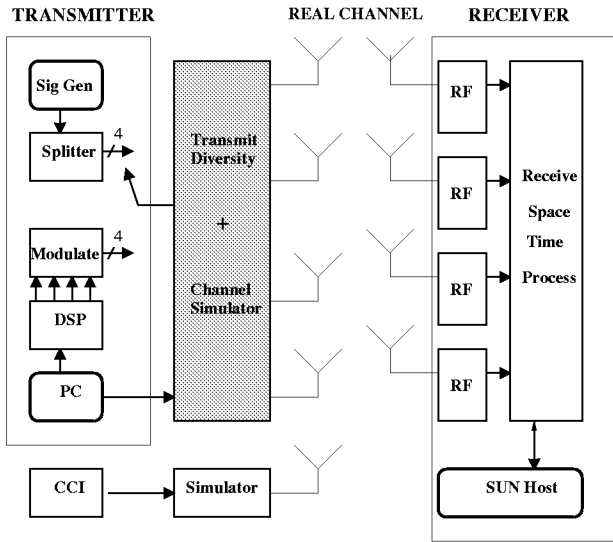


Figure 1: SU Testbed Architecture

2.2. Channel

A hybrid channel model which is a combination of real physical channel and a full spectrum simulated channel is used, as illustrated in Figure 1. The RF output(s) from the transmitter is first passed through the channel simulator. Up to 4 multipaths can be generated. Digital attenuators simulate Rician/Rayleigh fading on each path with variable average power. Doppler spread of up to 125 Hz and path correlation between 0 and 1 can be generated. Surface acoustic wave (SAW) delay lines provide delay spread of up to 5 micro seconds. The multipath outputs from simulator are then launched into the real channel using separate antennas. Angle spread of up to 30 degrees can be created by spatially separating the antennas.

CCI is created by feeding a signal generator output to a similar RF channel simulator and then transmitting on a separate antenna. The signal carrier to interference ratio can be adjusted by regulating the output power on the signal generator. Alternatively, a real mobile phone that can be programmed to operate in a test-mode with varying RF output power can also be used to generate CCI. In this case, the mobile unit is shielded and a connectorized output is fed to the hybrid channel.

2.3. Receiver

The receiver can handle data from up to 4 receiving antennas. Each input is pre-amplified and downconverted to IF (540 KHz) in 2 stages before feeding the signal to an A/D converter in the data processing unit.

The data processing system features a VME backplane with the following features:

- A VME Master DSP board (2 C40 processors) and high speed VME A/D board (up to 20 MHz sampling rate, up to 8 channel I/O) with SUN host for monitoring system status.

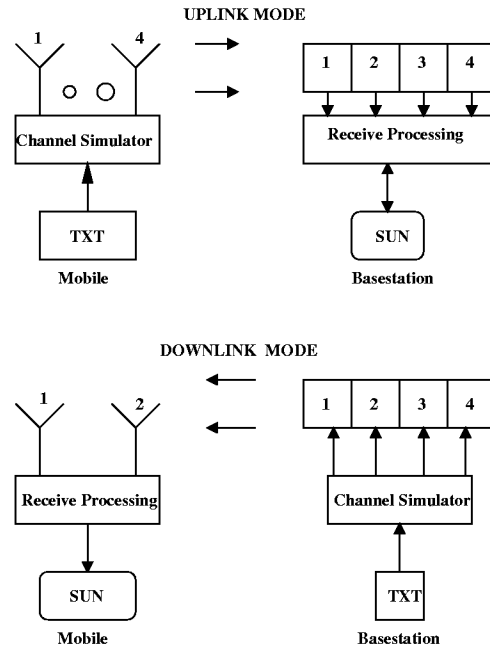


Figure 2: Uplink and Downlink Operation

- High speed 4-channel parallel data transfer (20 MB/s) between master board, A/D board and a series of 8 QUAD boards (4 C40 DSPs each).
- Parallel processing of 4-channel data by 4 DSPS in each QUAD board.

This parallel data transfer and processing architecture enables multiple algorithms to be simultaneously implemented in real-time. In the development stages of new algorithms, it is often useful to directly test MATLAB code in the testbed and have graphical display and control of receiver parameters. The processing system can be configured to provide a quasi-real time processing mode with MATLAB processing capability on SUN host. The VME system transfers bursts of data to SUN for processing. Subsequent bursts are delivered only after the processing is complete on SUN. This means several data bursts are skipped before one burst is randomly selected for processing (quasi-real time).

3. OPERATIONAL MODES

The testbed can be operated in either uplink and downlink modes with minimal hardware changes as shown in Figure 2.

For uplink, the 4 RF receiver inputs are connected to an array of 4 patch antennas to form the base-station receiver. Each patch antenna has 120 X 120 degree beam pattern with vertical polarization and 4 dB antenna gain. The multi-path outputs from the channel simulator are connected to omni-antennas to create a mobile transmitter launching signals in different channel scenarios. For downlink, the antenna configuration is reversed. The patch antennas are connected to the channel simulator outputs to form the basestation transmitter. Two closely spaced omni-antennas are connected to

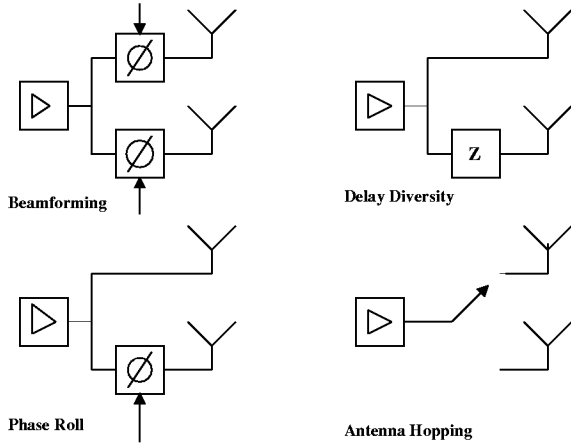


Figure 3: Transmit Processing Schemes

the receiver to form the mobile receiver.

4. ALGORITHMS IMPLEMENTED

Various STP schemes for transmit and receive diversity, CCI and ISI mitigation and array gain, have been implemented in the SU testbed.

4.1. Transmit Processing

Two types of transmit STP are possible. If the transmit channel is known, the antennas can be driven with complex conjugate weighting to co-phase the signal at the receiver. If the forward channel is not known, then the space diversity in the transmitter is converted to other forms of diversity exploitable in the receiver (transformed diversity)[8]. Some of the transmit schemes are illustrated in figure 3. Note that the beamformer algorithm assumes channel knowledge, whereas the other schemes described below do not.

- **Beam Forming [7]:** The transmit beam pattern is made directional, i.e; the energy coupled into each of the multipaths is selectively weighted. If space-only time processing is employed, the beamforming vector is fixed in time, but if STP is used, it is time-varying. This technique maximizes the received signal level and minimizes the interference created at other receivers.
- **Delay Diversity [8]:** In this method, space-diversity is transformed to path diversity at the receiver. The signal is transmitted over multiple antennas with delays of the order of symbol period. This forced delay spread creates independently fading multipath arrivals that can be resolved with an MLSE equalizer at the receiver.
- **Antenna Phase Rolling/Antenna Hopping [8]:** The coded and interleaved data is randomly switched between antennas or subject to random phase roll before transmission. The space-selective fading at the transmitter is converted to time selective fading at the receiver, where a channel decoder can be used to give performance gain.

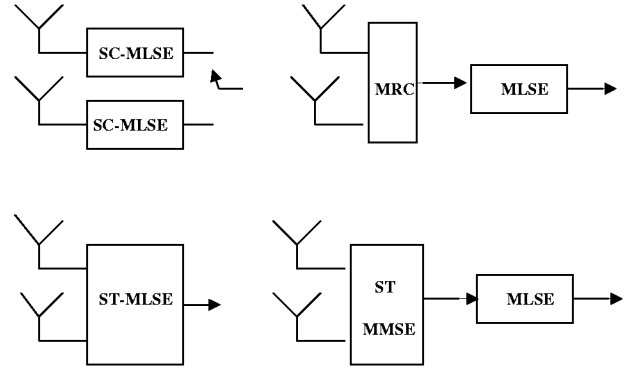


Figure 4: Receive Processing Schemes

- **Space-time coding :** The coded data is split into multiple streams and simultaneously modulated and transmitted on different antennas. Since different branches fade independently, space diversity is converted to time diversity at the receiver, which employs channel decoding to recover the data sequence.

4.2. Receive Processing

The receiver schemes are illustrated in figure 4

- **Single Channel (SC) MLSE:** In this scenario, MLSE (Maximum likelihood sequence estimation) is performed on each channel input for ISI mitigation. Path diversity is obtained if delay diversity is artificially created by the transmitter. Selection diversity is obtained by choosing the best MLSE output from all channels. This temporal receiver is ineffective in cancelling CCI.
- **MRC-MLSE:** MRC (Maximum ratio combining) is performed over antenna inputs to provide array gain and spatial diversity. MLSE is then performed over the combined output for ISI-mitigation.
- **ST-MLSE:** A joint spacetime MLSE is performed over all the antenna inputs to provide ISI mitigation, spatial diversity, and array gain. If delay diversity is employed in transmitter, then a transformed path diversity is obtained at the receiver. This scheme is not effective in cancelling CCI with delay spread.
- **ST-MMSE-MLSE [6]:** This hybrid approach combines the strengths of MMSE and MLSE receivers. An MMSE spacetime filter is used to suppress CCI and then the residual ISI is removed using MLSE processing. Space diversity and array gain is also obtained. Path diversity is obtained if delay diversity is employed in transmitter.

5. PRELIMINARY RESULTS

The capabilities of different transmit and receive schemes were demonstrated in the Smart Antenna Workshop held at Stanford University [9]. We demonstrated that ST-MLSE gives superior

performance in terms of ISI mitigation and path diversity, when compared to single-channel MLSE. The capability of ST-MMSE-MLSE receiver to effectively cancel CCI was demonstrated. Final results will be presented in future publications.

6. SUMMARY

The SU testbed is a rapid prototyping system designed to evaluate a wide range of STP algorithms. It can operate both in uplink and downlink mode with minimal hardware changes. Real-time operation of multiple algorithms is made possible through a parallel DSP architecture. A quasi-real time operational mode with MATLAB processing and graphics capability is also possible. The testbed uses a hybrid channel model that combines a real channel and a simulated channel, which allows to test STP algorithms in a wide range of realistic wireless environments. Different STP schemes that have been implemented are discussed. The preliminary results were presented in the Smart Antenna Workshop held at Stanford University [9]

7. ACKNOWLEDGMENTS

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