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Smart Antenna Experiments for 3G and 4G Cellular Systems

3G is an ITU specification for the Third Generation of mobile communications technology. Analog cellular was the first generation (1G) and digital PCS, what we have now in the U.S., is the second generation (2G).

The third generation promises increased bandwidth up to 384 kbits/sec for wide area coverage and up to 2 Mbits/sec for local area coverage. 3G will work over wireless interfaces such as GSM, TDMA and CDMA and will provide simultaneous voice and data services. The new EDGE interface (See Terms on p. 2) has been developed specifically to meet the bandwidth needs of 3G. 3G technology has been introduced in Japan in the Spring of 2001. It is not expected to reach the U.S. until 2003.

Fourth generation (4G) wireless technologies will provide data rates similar to office LANs or home cable modems and would be complementary to emerging 3G services. Several approaches are possible, ranging from a high-speed system very closely integrated with expected 3G options to a completely new high-speed packet data system.

Smart antenna techniques, such as multiple-input multiple-output (MIMO) systems, can extend the capabilities of 3G and 4G systems to provide customers with increased data throughput for mobile high-speed data applications. MIMO systems use multiple antennas at both the transmitter and receiver to increase the capacity of the wireless channel. With these techniques, it may be possible to provide in excess of 1 Mbit/sec for the 3G wireless TDMA system EDGE and as high as 20 Mbits/sec for 4G systems.

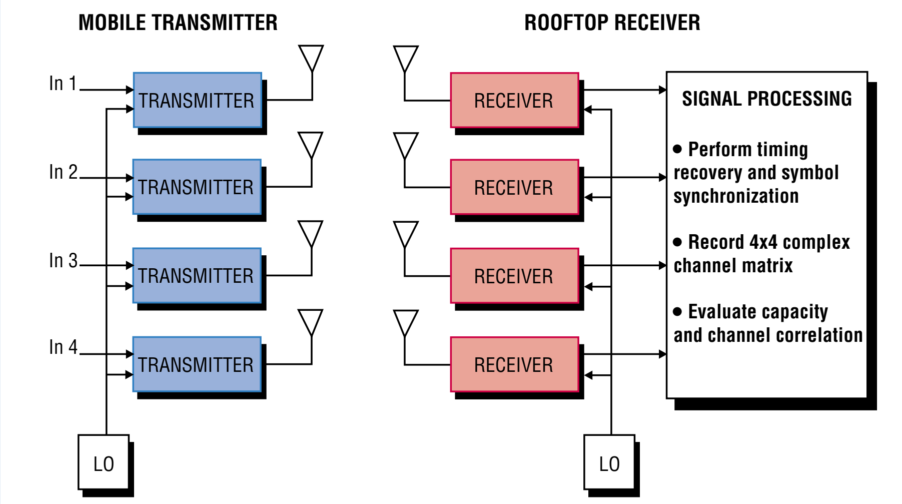


Figure 1. MIMO Test System

Smart Antenna Experiments

Researchers at AT&T Labs-Research in Middletown, NJ have conducted field tests to characterize the mobile MIMO radio channel. They measured the capacity of a system with four antennas on a laptop computer and four antennas on a rooftop base station. The field tests show that close to the theoretical fourfold capacity increase over a single-antenna system can be supported in a 30 kHz channel with dual-polarized spatially-separated base station and mobile terminal antennas.

Measurements were taken under a variety of test runs such as suburban drives, highway drives, and pedestrian routes. These results show that with the appropriate antennas, it may be possible to provide 1 Mbit/sec or more in a 200 kHz mobile radio channel to meet the 3G wireless TDMA system EDGE requirements.

To test the performance of MIMO, they built a real-time experimental system with multiple antennas at both the transmitter and the receiver. With MIMO, different signals are transmitted out of each antenna simultaneously in the same bandwidth and then separated at the receiver. With four antennas at the transmitter and receiver, this has the potential to provide four times the data rate of a single antenna system without an increase in transmit power or bandwidth. MIMO techniques can support multiple independent channels in the same bandwidth, provided the multipath environment is rich enough. What this means is that high capacities are theoretically possible, unless there is a direct line-of-site between transmitter and receiver.

Test System

The test system shown in Figure 1 consists of a 4-branch base station receiver with rooftop antennas and a 4-branch transmitter mobile system with antennas mounted on a laptop computer. The hardware associated with the system is shown in the composite photograph of Figure 2 on page 2.

Four coherent 1 watt 1900 MHz transmitters were used in the mobile equipment and four coherent 1900 MHz receivers were used in the base station. Real-time baseband processing using a Pentek 4270 Quad ’C40 DSP board was used to do filtering, synchronization,

Smart Antenna Experiments for 3G and 4G Cellular Systems

Figure 2. Upper: Transmitter with four antennas on a laptop and the 1900 MHz coherent transmitters. Lower: The four receivers with real-time baseband processing and the rooftop antennas (Courtesy of AT&T Labs-Research).

[Continued from page 1]
tracking, and to correlate the complex-baseband signals at each receive antenna.

The base station rooftop antenna array used dual-polarized antennas separated by 11.3 feet, which is approximately equal to 20 wavelengths, and a multibeam antenna. The laptop-mounted antennas included a vertically-polarized array and a dual-polarized array with elements spaced a half wavelength apart.

Signal Processing

The tests were conducted by transmitting bit and frame synchronous 8-symbol Walsh sequences. Walsh functions are binary orthogonal sequences with power-of-two lengths. A different Walsh sequence was transmitted out of each antenna with a symbol rate of 24.3 ksymbols per second in a 30 kHz bandwidth.

Figure 3 is a simplified block diagram of the baseband processing system. The downconverted receiver signals are correlated in each DSP of the Model 4270 Quad 'C40 DSP board in real time with each of the four Walsh sequences. The

Some Cellular Terms

ITU is the International Telecommunications Union, an intergovernmental organization through which public and private organizations develop telecommunications. Founded in 1865, it became a United Nations Agency in 1947. It is responsible for adopting international treaties, regulations and standards that govern telecommunications. The standardization functions were performed by the CCITT group within the ITU, but after a 1992 reorganization the group no longer exists as a separate body.

PCS is short for Personal Communications Service, the U.S. Federal Communications Commission (FCC) term used to describe a set of digital cellular technologies that have been deployed in the U.S. in the last few years. PCS works over CDMA (also known as IS-95), GSM, and North American TDMA (also known as IS-136, see Pipeline Vol. 8 No. 2, Summer 1999). Some of the most important features of PCS systems are:

- They are completely digital
- They operate in the 1900 MHz range
- They can be used internationally

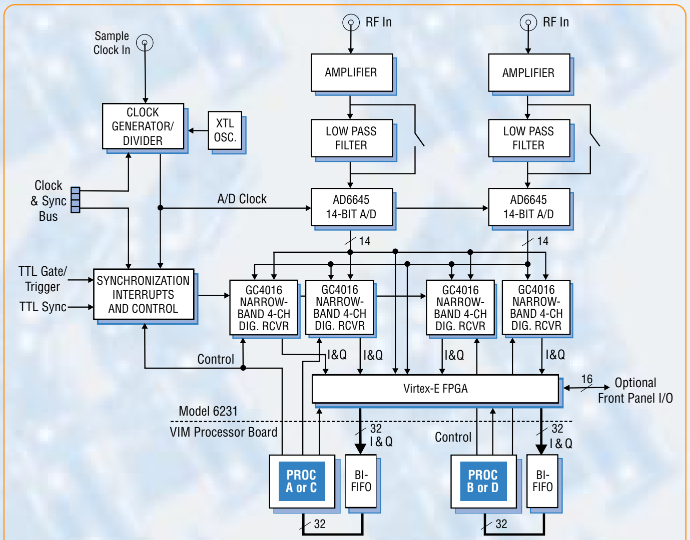
GSM stands for Global System for Mobile communications and is one of the leading cellular systems. Introduced in 1991, GSM service was available in more than 100 countries by the end of 1997 and has become the de facto standard in Europe and Asia. GSM uses narrowband TDMA that allows eight simultaneous calls on the same radio frequency.

TDMA is short for Time Division Multiple Access, a technology for delivering digital wireless service using time-division multiplexing (TDM). TDMA divides a radio frequency into time slots and then allocates the slots to multiple calls. This way, a frequency can support multiple simultaneous data channels. The GSM cellular system uses TDMA.

CDMA stands for Code Division Multiple Access, a digital cellular technology that uses spread-spectrum techniques. Unlike systems such as GSM that use time-division multiplexing, CDMA does not assign a specific frequency to each user. Instead, every channel uses the full available spectrum and individual conversations are encoded with a pseudorandom digital sequence.

EDGE stands for Enhanced Data rates for Global Evolution. As stated in the opening paragraph, it's an interface developed specifically to meet the bandwidth requirements of 3G.

16-Channel Digital Receiver VIM-2 Module



Model 6231 Block Diagram

Two Model 6231's may be attached to a VIM-compatible processor board to provide 32 receiver channels in one slot. Alternately, the 6231 may be combined with another VIM-2 module to provide additional I/O options.

[From page 4]

FPGA

The receiver outputs are delivered to a Xilinx Virtex-E FPGA (field programmable gate array) which performs various modes of data packing, formatting and channel selection. The A/D outputs are also connected directly to the FPGA so that wideband A/D data can be delivered directly to the processor, bypassing the digital receivers.

Optionally available design kits allow the FPGAs to be configured by the user for implementation of custom preprocessing functions such as convolution, framing, pattern recognition and decompression.

VIM Processor Interface

The FPGA output is connected directly through the VIM mezzanine interface to the 32-bit synchronous FIFO on the VIM processor board where it is buffered for efficient block transfers into the processor. The processor can control the programmable registers on its associated GC4016's as well as control and initiate sync bus functions.

Pentek's ReadyFow™ Board Support Libraries are available for this product.

For more information on the 6231 or any of our VIM products, visit our website at **http://www.pentek.com.** ❑

complex correlation of each transmit waveform on each antenna is then recorded to disk at 3038 (≈24,300/8) samples per second.

Results

Drive tests plus pedestrian and indoor tests were conducted at 1900 MHz at various distances from the base station which is located in a suburban environment. Data was collected along several routes including routes in a residential area and on a highway with vehicle speeds of 30 and 60 mph and distances from the base station of 2 to 5 miles. Pedestrian tests were conducted by walking with the mobile terminal at several locations and also by placing it inside a house.

The upper graph of Figure 4 shows the capacity measured with the MIMO system, normalized with respect to a single-input single-output system capacity vs. time; the lower graph shows correlation vs. time, for one of the residential drive routes. The capacity does not vary significantly and is close to 3.77 even at correlation coefficients as high as 0.5.

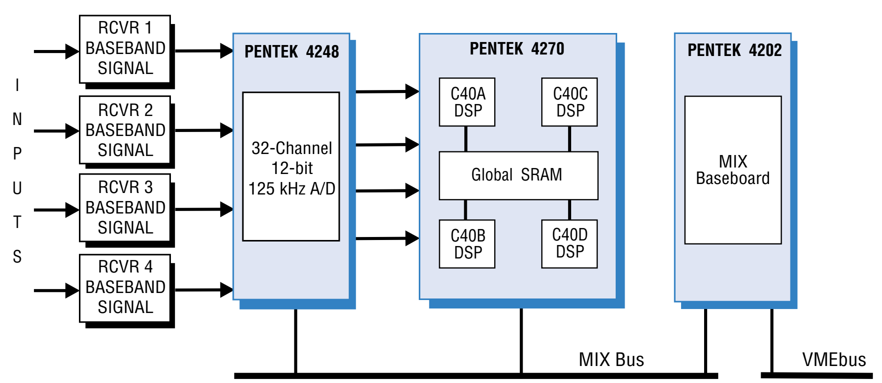


Figure 3. Block Diagram, Receiver Signal Processing

The capacity and correlation values were averaged over one second.

The results indicate that the multipath environment is rich enough to support 4x4 MIMO in the vast majority of the locations. These results are valuable inputs to the design, development, and deployment of multi-antenna systems that could substantially increase the data rate and capacity of future cellular systems. MIMO for mobile applications is an exciting research area and may become a key technology for future wireless systems. ❑

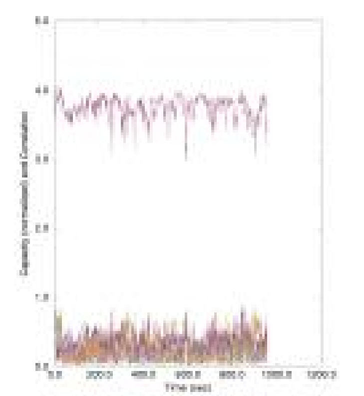


Figure 4. System Capacity & Correlation (Courtesy of AT&T Labs-Research).

Product Focus

Model 6231

16-Channel Digital Receiver VIM-2 Module

Includes RF amplifiers, A/Ds and FPGA for custom processing functions

Model 6231 is a general-purpose 16-channel narrowband digital receiver VIM-2 module. It attaches directly to VIM-compatible processor boards and connects directly to two processors.

Model 6231 accepts two analog RF inputs on front panel SMA connectors in the range of DC to 90 MHz to support direct IF undersampling. Each input is amplified and then, optionally, lowpass filtered to avoid aliasing of baseband signals.

The two inputs are then digitized by two AD6644 or AD6645 14-bit A/D converters operating at 64 MHz or 80 MHz respectively. The sampling clock can be driven from an internal crystal oscillator or from an external clock source supplied through a front panel SMA connector.

Digital Receivers

The 6231 includes four 80 MHz Graychip GC4016 quad narrowband digital receiver chips. Each device includes four independently tuned receiver channels capable of center frequency tuning from DC to 40 MHz, and output bandwidths from 4 kHz to 2 MHz (for 80 MHz sample clock).

Each GC4016 accepts two 14-bit parallel inputs from the four A/D converters. An internal crossbar switch allows all 16 receiver channels on the board to select either of the A/D inputs for flexible switching.

Synchronization

The front panel clock and sync bus allow one 6231 to act as a master, driving the sample clock out to a front panel cable bus using LVDS differential signaling. Multiple slaves can then be clocked synchronously with the master.

Additional sync lines allow synchronization of the local oscillator phase, frequency switching, decimating filter phase, and FIFO data collection. ➤

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