Using Base Station and MIMO Channel Emulators to Characterize Performance of a Mobile WiMAX Device

This article describes how a channel emulator can be used to characterize the performance of a MIMO receiver. The testing was done in stages of increasing complexity, namely testing under AWGN conditions, MIMO testing with known static channels, and finally testing with channels chosen to represent "real world" behavior. The article seeks to demonstrate how testing at each of these stages can help give engineers confidence in their design as well as potentially expose issues that may be difficult to isolate with the more complex "real world" testing.

The IEEE 802.16 working group is focused on developing standards for Broadband Wireless Access. As a part of this work, a physical layer specification has been written for mobile devices,[1] which uses Orthogonal Frequency Division Multiple Access (OFDMA) in combination with advanced techniques such as Adaptive Modulation and Coding (AMC) and multiple input, multiple output (MIMO). The overall performance gain for a network that uses techniques such as AMC and MIMO is strongly influenced by the receiver characteristics of client devices within that network. For example, a good receiver will allow the network to more readily use complex modulation schemes and hence achieve greater throughputs. This article uses the combination of a base station emulator and a MIMO channel emulator to characterize the receiver performance of a commercially available Mobile WiMAX device.

MEASUREMENT SET-UP

Figures 1 and ***2*** show a schematic representation and a photograph of the equipment used for the testing. The E6651A is a fully functional base station emulator designed for testing mobile WiMAX devices. It supports a number of different use models, including RF testing, functional emulation of protocol features, end-to-end application testing and protocol conformance testing. In this case, the equipment was used to perform a downlink "ping test", with a variety of different modulation and coding formats both with and without MIMO.

The E6651A has two RF ports that can be configured to provide transmitter outputs for MIMO testing. Each downlink signal was fed into a signal analyzer (MXA) that down-converted the RF signal to a differential baseband digital signal that served as an input to the PXB.

The N5106A PXB MIMO Receiver Tester is a baseband channel emulator that allows the user to emulate a variety of single channel and MIMO fading conditions. In addition to channel characteristics, such as Doppler spread and delay spread, the PXB is able to emulate antenna characteristics, including antenna spacing, polarization, antenna lobe patterns and angular spread. The PXB can be used in a baseband configuration, where it is connected to a signal source (MXG) and used to test receiver perfor-

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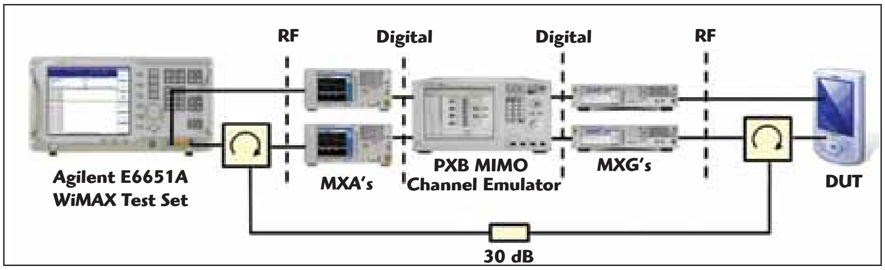
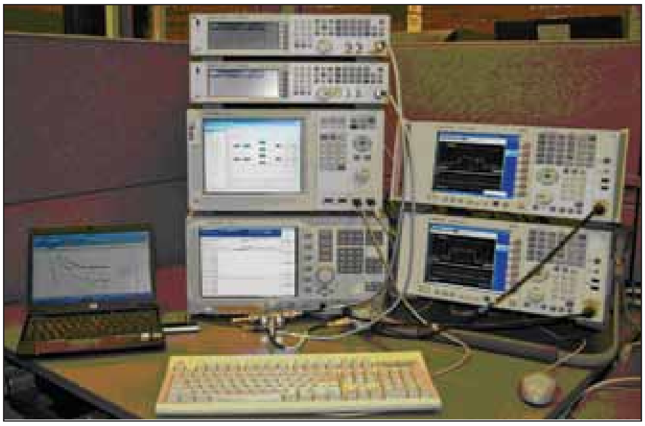
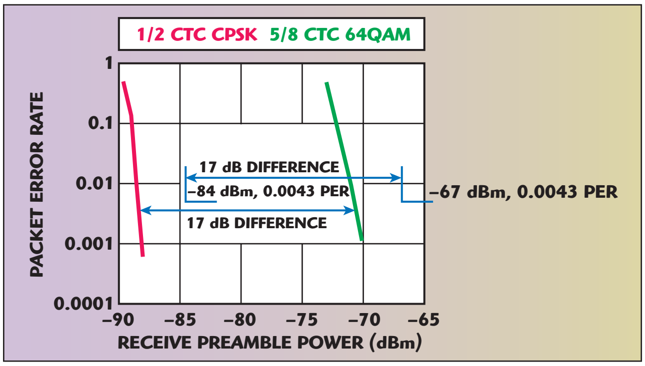


▲ *Fig. 1 Equipment set-up for measuring receiver performance.*



▲ *Fig. 2 Photograph of the measurement set-up used for receiver testing.*



▲ *Fig. 3 Packet error rate under AWGN conditions.*

mance for a variety of different wireless formats.

In this test set-up the digital outputs from the PXB were up-converted to RF using a signal source and then connected with the device under test (DUT). In order to support a fully functional radio, the cabling set-up uses isolators to provide an un-faded uplink signal to the RF1 port of the E6651A.

THERMAL NOISE PERFORMANCE

Figure 3 shows the sensitivity measurements for the device under test under thermal noise conditions. The figure is also annotated to show the test limits as defined by the WiMAX Forum in its Radio Conformance Test (RCT) specification.[2]

These results demonstrate that the receiver is meeting the required sensitivity limits under additive white Gaussian noise (AWGN) conditions. The WiMAX Forum test limits are set by calculating the theoretical thermal noise power and then assuming degradation due to the noise figure of the receiver and an implementation loss. Passing this test provides a level of confidence about both the device and the measurement set-up.

MIMO PERFORMANCE UNDER STATIC FADING CONDITIONS

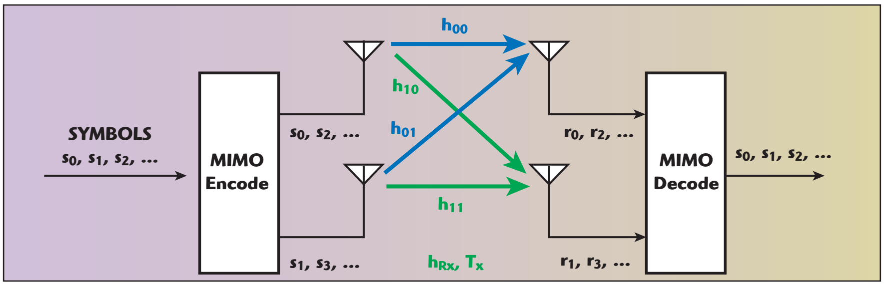
MIMO techniques exploit the multipath characteristics of radio channels and allow the link to either benefit from higher orders of diversity or to create separate spatial streams, which can support the transmission with increased data throughput. The use of spatial streams for increasing data throughput is an exciting development which, given the right conditions, provides the possibility of achieving data rates that exceed the Shannon Capacity limit.

Given that MIMO is exploiting the characteristics of a multipath channel, it is not possible to characterize the performance using a simple AWGN channel. However, prior to testing the performance in channels that are intended to emulate "real world" environments, it is helpful to test the MIMO performance in simple static channels, where the expected behavior is known.

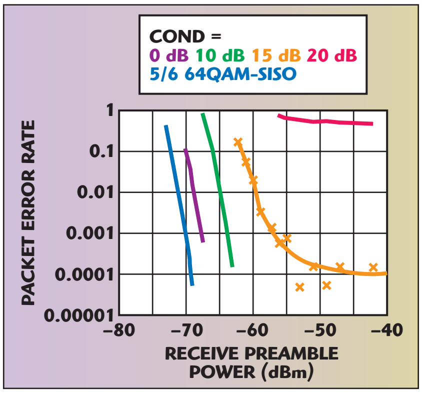
One way of characterizing whether or not a "channel" is well suited to providing multiple spatial streams is to calculate the condition number.[3] The condition number is a measure of how sensitive the eigenvalues of a given matrix are to small perturbations of the values in that matrix. If the condition number is low then the eigenvalues will not be sensitive to small perturbations (or noise) and the channel will be well suited to supporting two MIMO streams. A high condition number indicates that the channel matrix is very sensitive to noise and the system requires a significant increase in the required signal to noise ratio in order to support multiple spatial streams.

Figure 4 shows a schematic representation of a 2 × 2 MIMO channel. Each of the Tx-Rx pairs has their own channel, which in the general case can be represented by a complex time varying impulse response. For the simplified static channels h00, h01, h10 and h11 can each be represented by a constant complex number within a single matrix. The matrix (1,0,0,1) has a condition number of 0 dB and reflects a theoretically perfect MIMO channel with two spatial streams, which are orthogonal. The packet error rate curves in ***Figure 5*** show a shift in the required SNR for a single input, single output (SISO) link vs. an ideal MIMO link with two transmitters and two receivers (condition number = 0 dB). The figure also shows curves for packet error rates for a variety of channels with varying levels of condition number.

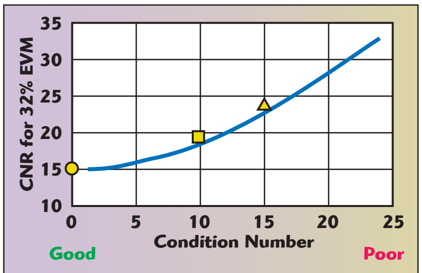
Cain[3] has plotted graphs to show the empirical relationship between the condition number and the additional carrier to noise required to maintain a given error vector magnitude (EVM). ***Figure 6*** shows an example where the blue line corresponds to the additional CNR required to sustain an EVM of 32 percent. Placed on this graph are three data points (shown as a yellow circle, square and triangle), which overlay the measurements presented in this article. This shows a good correlation between the SNR required for a given EVM vs. those related to specific bit error rate curves. The figure also shows that, for a practical receiver implementation at high condition numbers, MIMO techniques fail to provide a useable benefit



▲ *Fig. 4 2 × 2 MIMO channel.*



▲ *Fig. 5 MIMO performance in static channels with varying condition numbers.*



Condition Number	Delta CINR
0 dB	0 dB ○
10 dB	4.5 dB □
15 dB	9 dB △
25 dB	Irreducible

Modulation & Coding: 5/6 Rate 64QAM, Per 10%

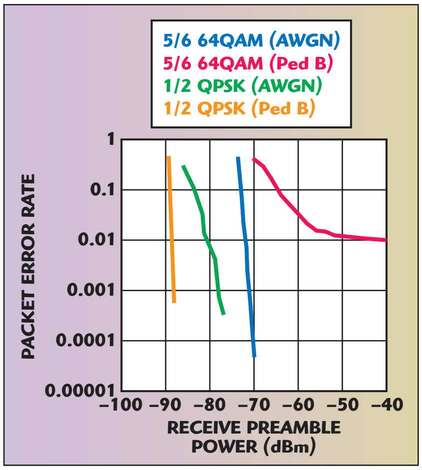
▲ *Fig. 6 Increased SNR requirements vs. condition number.*

as the system suffers from irreducible error rates (see curve for condition number = 25 dB).

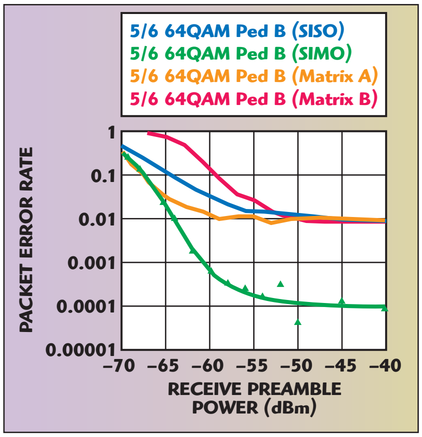
RECEIVER PERFORMANCE IN AN ITU-PEDB CHANNEL

Testing with static channels is instructive as it allows comparison between measured results and the theory of MIMO operation. However, in order to assess the expected performance of a given system, it is necessary to emulate time varying "real world" channels. In this article, an ITU pedestrian profile B (mobile speed of 3 km/h) was used as one example of a real world channel.

Figure 7 shows the SISO receiver



▲ *Fig. 7 QPSK vs. 64QAM under noise and pedestrian B conditions.*



▲ *Fig. 8 WiMAX MIMO receiver performance.*

performance for both ½ rate QPSK and $^5/_6$ rate 64QAM under both AWGN and pedestrian B channel conditions. For the $^1/_2$ rate QPSK, the sensitivity is degraded by approximately 8 dB, using the pedestrian B channel at the 1 percent PER level. For $^5/_6$ rate 64QAM, the receiver suffers from an irreducible error rate when measured under pedestrian B channel conditions. To verify this result the measurement was repeated on a different DUT and similar results were found.

Figure 8 shows the $^5/_6$ rate 64QAM performance with a variety of SISO/MIMO configurations. The green line for SIMO shows the benefit of Rx diversity with the irreducible PER reduced to only 0.1 percent. This is expected theoretically if the errors on each of the channels can be considered to be mutually exclusive random variables (that is 0.01 × 0.01 = 0.0001). Interestingly, if Matrix A MIMO is employed (that is transmit diversity), the irreducible error rate is 1 percent and not 0.01 percent achieved with Rx diversity. This could be explained by quantization issues during deep fades as, for Tx diversity, each Rx has to extract the two Tx signals from one sampled waveform, which is not required in simple Rx diversity. Matrix A MIMO does, however, demonstrate a diversity gain versus the blue SISO curve. Given that WiMAX networks seek to optimize approximately a 10 percent PER, the Matrix A performance gain will be valuable to the system. Finally, Matrix B MIMO demonstrates that even under these Ped B channel conditions, it is possible to double the data throughput. There is, however, a penalty in terms of the required signal to noise.

CONCLUSION

This article has shown how a base station emulator can be used in conjunction with a channel emulator to characterize the performance of a MIMO capable receiver. Measured results were compared with theory for both AWGN and static MIMO channel conditions. Finally, this article presents MIMO receiver performance results using the ITU pedestrian B profile. This work shows how the ITU pedestrian B profile does stress the receiver (witnessed by the presence of an irreducible error rate), but that it is still possible to exploit the benefits of both receive diversity and MIMO in this radio environment. ■

ACKNOWLEDGMENT

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