From SISO to MIMO – taking advantage of everything the air interface offers (2)

Part 1 of this article in number 192 discussed SISO, SIMO and MISO systems (see box below) and how they are used in GSM, WCDMA and WiMAX. The tests defined as part of the certification process were also discussed along with how they can be implemented using instruments from Rohde & Schwarz. Part 2 will cover MIMO systems, i.e. the variants used in the different standards, the relevant test scenarios and their implementation.

MIMO (multiple transmitting and receiving antennas)

MIMO systems have also made their way into test specifications, and the day when these multiple antenna systems will actually see real-world implementation is nearing. In MIMO, N transmitting antennas provide signals to M receiving antennas (FIG 2). In general, the transmission channel in a MIMO system can be characterized using the following $N_r \times N_t$ channel matrix $\mathbf{H}(\tau,t)$:

$$\mathbf{H}(\tau,t) = \begin{bmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & \cdots & h_{1,N_t}(\tau,t) \\ h_{2,1}(\tau,t) & h_{2,2}(\tau,t) & \cdots & h_{2,N_t}(\tau,t) \\ \vdots & \vdots & & \vdots \\ h_{N_r,1}(\tau,t) & h_{N_r,2}(\tau,t) & \cdots & h_{N_r,N_t}(\tau,t) \end{bmatrix}$$

The elements of the main diagonal $h_{i,i}$ characterize the direct transmission paths between the antennas, and the remaining elements characterize the mixing products. We thus obtain the received signal $\mathbf{r}(t)$ as follows:

$\mathbf{r}(t) = \mathbf{H}(\tau,t) \times \mathbf{s}(t) + \mathbf{n}(t)$,

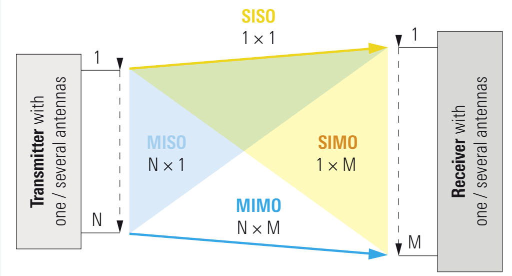
where $\mathbf{H}(\tau,t)$ channel matrix
$\mathbf{s}(t)$ transmitted signal
$\mathbf{n}(t)$ additive noise

In MIMO, all of the basic concepts discussed in Part I are combined in different ways. Depending on the actual technique, the result is either higher data throughput or more robust transmission.

Logically, it makes sense to exploit favorable transmission conditions to increase the transmission rate by selecting the corresponding technique. Under less favorable transmission conditions, however, this does not produce the desired result. In these cases, we need to choose a technique that increases the transmission reliability. Increased transmission reliability also has a positive effect on the data throughput since less channel capacity is wasted to repeat blocks with errors.

Since the properties of a transmission channel can fluctuate very quickly, any change in the transmission technique must be carried out quickly as well. This requires fast feedback of the channel properties from the receiver to the transmitter, which means that the timing needs for such feedback must be properly defined.

FIG 1 The different diversities at a glance.
The terms input and output always refer to the transmission channel. For the downlink (transmission channel from base station to mobile station), an input is a transmitting antenna of the base station and an output is a receiving antenna of the mobile station.



From SISO to MIMO – diversities at a glance

SISO Single Input Single Output The classic and easiest way: one transmitting and one receiving antenna.

SIMO Single Input Multiple Output One transmitting and several receiving antennas. Is also often referred to as receive diversity. With reference to the downlink, this means one transmitting antenna at the base station and more than one receiving antenna at the mobile radiotelephone.

MISO Multiple Input Single Output Several transmitting antennas and one receiving antenna. Is also referred to as transmit diversity. With reference to the downlink, this means more than one transmitting antenna at the base station and one receiving antenna at the mobile radiotelephone.

MIMO Multiple Input Multiple Output Complete expansion: N transmitting antennas provide signals to M receiving antennas.

Transmit diversity with space time block coding

The same data stream is transmitted using different antennas with different encoding (STTD – space time transmit diversity or space time block coding as described by Alamouti). This means that the receiver receives multiple copies of the same signal due to multipath propagation. This improves the signal-to-noise (S/N) ratio and makes the connection more stable. The less correlated the fading channels are, the greater the improvement. Note that it is not possible to continue improving the S/N ratio by adding more and more antennas. The system tends to become saturated.

Spatial division multiplexing

In this technique, the transmitting antennas simultaneously transmit multiple different data streams to one receiver. The receiver receives parallel data streams on each of its antennas. "All" the receiver has to do is separate these data streams. This is possible only under the assumption that channels with different fading are present on the different antennas (i. e. the lower the correlation, the better). This technique increases the data throughput, but it makes sense only under favorable transmission conditions. Here, too, the possible gain is limited by the correlation of the transmission paths.

Beamforming

In this case, signals are not transmitted omnidirectionally. Instead, antenna arrays produce an individual beam for each mobile station. This means that the base station orients its antenna array so that its transmission lobe tracks the movements of the mobile station. This, however, requires a signal that can be assigned by frequency and / or time to a mobile station. Otherwise stated: Each mobile station must have its own lobe. With GSM, for example, each mobile station is assigned a frequency (ARFCN, absolute radio frequency channel number) for a certain number of timeslots so that beamforming is possible. This is not the case with WCDMA since a mobile station is identified only by its code within a frequency or time range which it shares with other mobile stations. This makes it impossible for the base station to use its transmission lobe to track different mobile stations as they move about. As a basic prerequisite, the properties of the transmission channel must be known at the transmitter for a base station to be able to direct its antenna array toward a specific mobile station.

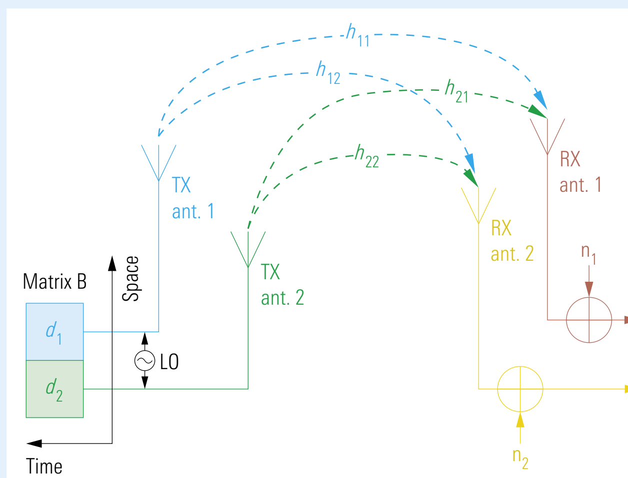
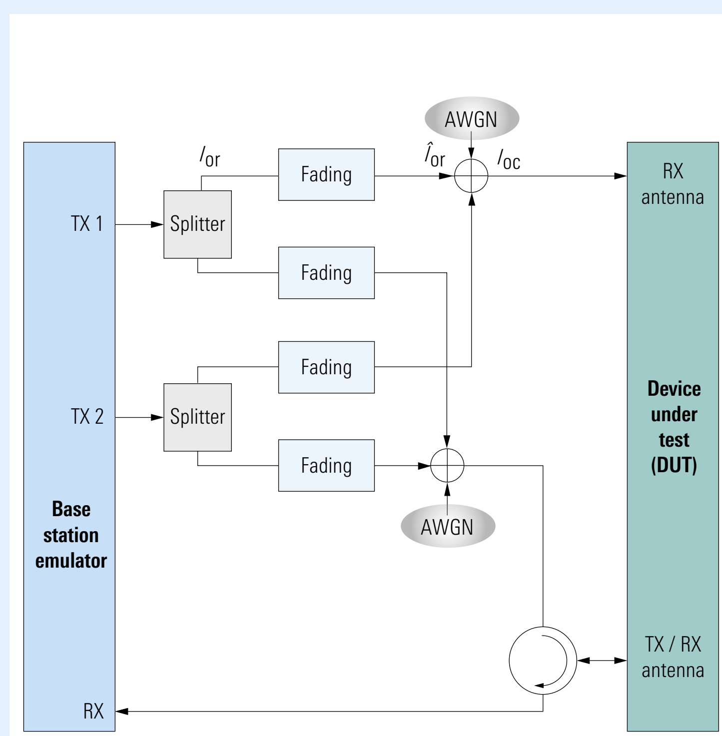


FIG 2
MIMO 2 × 2 with two transmitting and two receiving antennas.

FIG 3
Test setup for WCDMA MIMO in the downlink under multipath propagation conditions with transmit and receive diversity.



Currently defined test scenarios

GSM

After the test scenarios for a SIDO system (DARP phase 2), no additional steps toward MIMO are currently planned for GSM.

WCDMA

With its diversity performance tests 9.2.2C, 9.2.3C and 9.4.2A from release 7, WCDMA is introducing MIMO in the downlink (FIG 3). These tests are also part of work item 26 of the Global Certification Forum (GCF). Transmit diversity is used to improve the reception for a specific connection in the downlink. From the network operator's perspective, transmit diversity has the benefit that it does not require any changes in the transmission scheme used by the base stations.

Unlike the tests for DARP phase 2 in GSM, the fading channels are not correlated. Apart from an AWGN signal, no interferers are provided so far. FIG 4 shows the implementation of tests in accordance with WCDMA WI-26 using the R&S®TS 8950 W (FIG 4). With long term evolution (LTE) defined in release 8 of the 3GPP specifications, WCDMA continues to progress. The specifications for LTE are scheduled for completion in March 2008 and the associated tests should be ready by December 2008.

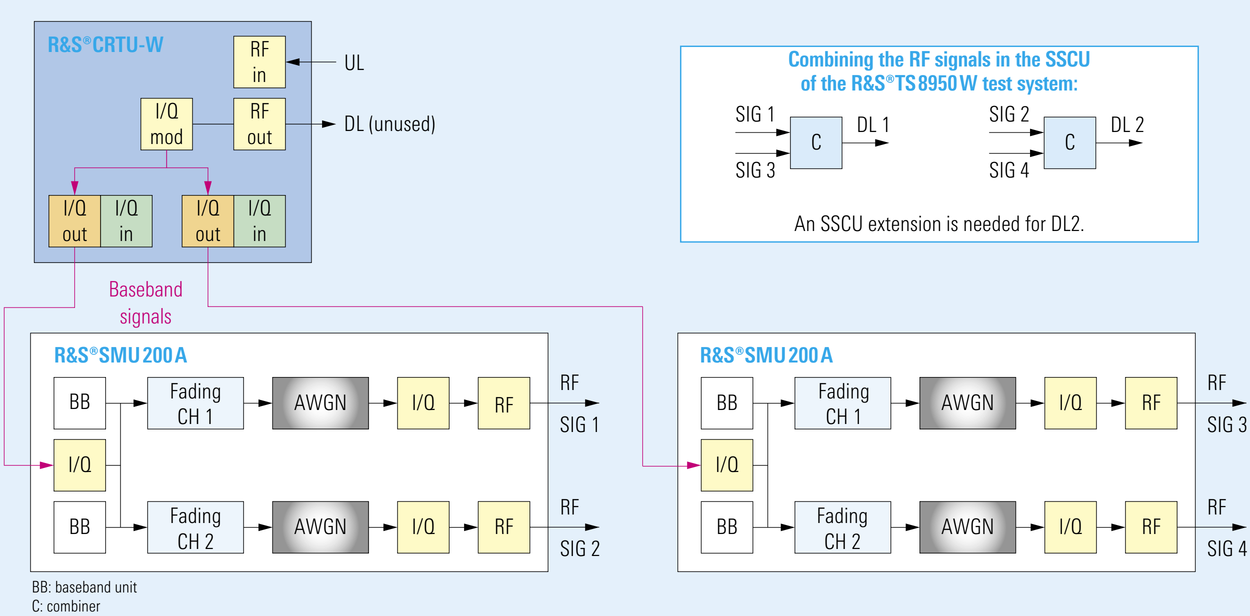
Since LTE, like WiMAX (IEEE 802.16e), is based on OFDMA, test scenarios similar to those described below for WiMAX Wave 2 will probably be used.

WiMAX (IEEE 802.16e)

The tests defined in Wave 1 are based on SISO (one transmitting antenna and one receiving antenna). According to the system profile for Wave 2, MIMO 2×2 will be used with two transmitting antennas and two receiving antennas including beamforming. An enhancement to MIMO 4×4 is already included in the IEEE 802.16e standard, and MIMO 8×8 is currently under discussion in the WiMAX® Forum. Since the principle is the same, we will not discuss these implementations in further detail here. The test scenarios for beamforming assume usage of up to four transmitting antennas per transmitter in the base station.

WiMAX makes a distinction between two MIMO modes: matrix A and matrix B. **Matrix A** is a transmit diversity mode in the downlink using space time coding in accordance with Alamouti which increases the stability of the connection under unfavorable conditions. **Matrix B** is a spatial multiple access technique that includes single as well as multiple code word transmission (also known as vertical and horizontal encoding) and increases the data rate under favorable transmission conditions. Switching between matrix A and matrix B depends on the properties of the transmission channel. The base station determines how long to use each mode. For

FIG 4 An R&S®CRTU-G /-W protocol tester and two R&S®SMU 200 A generators (also used as faders) generate the two downlink signals. An extension is needed in the signal switching and conditioning unit (SSCU) in the R&S®TS 8950 W test system to add up the two downlink RF signals and to provide a second DUT interface.



this purpose, it must know the transmit channel. Feedback of the reception quality is included in the signaling from the mobile station to the base station.

The approval tests that are specified verify the performance gain achieved by MIMO, e. g. the sensitivity with different modulation types, as well as the correct implementation of matrix A and matrix B and the switchover between them.

Beamforming

Beamforming tests for base stations use an approach that involves combining all antenna outputs of a transmitter in the test system with different electrical lengths. The base station needs to compensate for the different delays so that all signals arrive at the mobile station emulator (MSE) with the same phase and add up there. In the ideal case, the MSE then "receives" a multiple of the power corresponding to the number of antennas. Beamforming functionality is verified by assessing the gain in sensitivity.

MIMO 2×2 tests for WiMAX

The Wave 2 MIMO tests involve a 2×2 channel model using correlated fading (FIG 5). An R&S®AMU 200 A equipped with two external I/Q inputs and the -K74 option ("fading split mode") can perform a complete 2×2 MIMO channel simulation in conjunction with two RF output stages (FIG 6). The complex correlation matrix can be programmed as required. The WiMAX® Forum has defined three different matrices (low, medium and high correlation).

Summary

More than half a year has elapsed since Part I of this article was published. In the meantime, many tests have been defined (and many have also been discarded). Clearly, however, there is sustained forward momentum. Many ideas await their implementation. One thing is clear, however: Rohde & Schwarz is continuously developing its measuring instruments and approval test systems so as to always provide the required test capabilities plus future viability.

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FIG 5 Setup with 2×2 channel model and correlated fading for testing a base station with the R&S®TS 8970 test system.

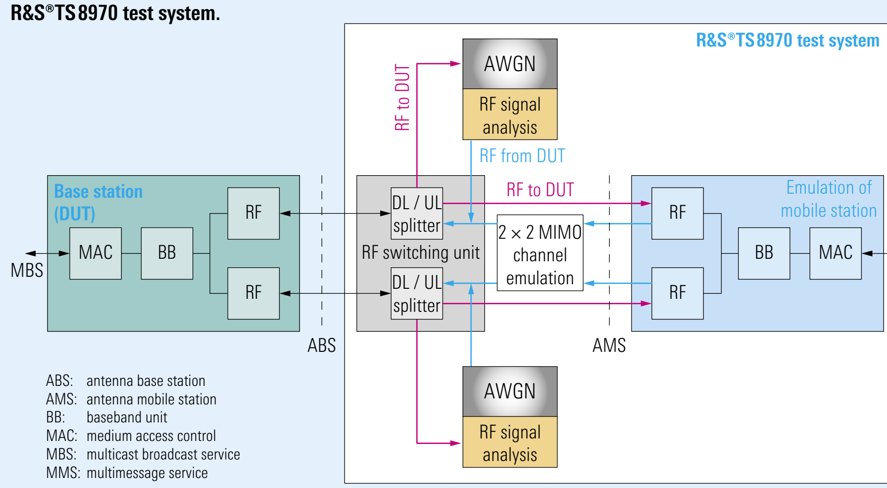

FIG 6 An R&S®AMU 200 A generator and two RF output stages simulate a 2×2 MIMO channel (the two R&S®SMU 200 A generators can also be replaced by an R&S®SMATE generator).