Detector design based on MIMO OTA test

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Abstract. The MIMO OTA test is currently one of the more mainstream test methods for multi-antenna terminal performance. However, in the MIMO OTA test, there are still problems such as complicated calculation amount and difficulty in realizing the model. This paper will optimize and improve the traditional MIMO OTA test method for the above problems, mainly using the PAS constraint. Finally, the optimized algorithm in this paper has made great progress in both the amount of calculation and the simplicity of the model.

1. Introduction
The multiple-input and multiple-output (MIMO) technique refers to transmit and receive signals through multiple antennas, which improves the communication quality. MIMO has become an essential element of wireless communication standards such as IEEE 802.11n, HSPA+, WiMAX and LTE 4G. It can make full use of space resources and multiply multiple antennas through multiple antennas. It can multiply the capacity of the system channel (data throughput, Qos and cell coverage) without additional transmit power or bandwidth. The MIMO technology is regarded as the core technology of the next generation mobile communication. Therefore, it is necessary to set a standard test method to test the MIMO device performance. There are many different MIMO test methods. Spatial correlation is a parameter including antenna and propagation characteristics. OTA test can test antenna and propagation effects in one testing time. Therefore, OTA test is a potential test method.

The cluster can be used to model the multipath problem. Each cluster is composed of the same PAS (power azimuth spectrum) scatter. The limited number of probes can be translated to an arbitrary number of clusters. The PAS has two parameters—angle of arrival and angle spread.

The power azimuth spectrum (PAS) plays a very important role in multi-antenna technology. The spatial correlation between the waves impinging on the two antenna elements depends on the PAS and radiation pattern of the antenna elements, spatial correlation is selected as the main figure of merit to character the channel spatial [1]. The channel will present different PAS when the sampling points are limited, although the spatial correlation is same. Therefore, a new method is proposed to solve the problem. We add constraints on the spatial correlation. The emulated PAS should be close to the target PAS in terms of mean angle of arrival (AoA) and azimuth spread (AS).

2. Background

2.1. 3GPP candidate test methodologies
The seven test methods were proposed to test the performance of MIMO. They can fall into two main type: Anechoic chamber methods and Reverberation chamber methods. The anechoic and reverberation methods are two fundamentally different approaches with same goal—the creation of a spatially diverse
radio channel. Anechoic chamber method is an effective method. Multiple probes are used to launch signals at the DUT in order to create known angles of arrival, which map onto the required channel spatial model [2]. However, large numbers of probes are required to achieve arbitrary channel model flexibility, which increases the cost and complexity. The reverberation chamber method provides a spatial richness through the natural reflection in the chamber, and further provides a space field by using an oscillating mode agitator, which is close to the isotropic field for a long time. The reverberation chamber can be used to measure the spatial multiplexing gain in the de-correlating antenna [2].

2.2. Configuration of MIMO OTA Setup
The set up of MIMO OTA test are showed in figure 1. The device under test (DUT) is in the center of the multiple probe anechoic chambers. The probes revolve around the DUT and are connected to the channel emulator. The BS emulator measures the signal for testing to the multi-channel emulator. The power amplifiers are required to make up for the path loss in the anechoic chamber [3].

In an emulated channel, the power weights are determined. I use prefaded signal synthesis technique (PFS) to radiate independent fading signals from multiple probes, a single cluster is mapped to multiple OTA probes based on PAS shape and OTA probe angle position to reconstruct PAS, appropriate average power weights should be allocated to the associated OTA probes when reconstructed the spatial characteristics at receiver [1].

3. Design and Implementation
In order to consider the influence of antenna correlation on performance, SCME channel model based on SCM model is selected as the target channel model for emulation. Considering the actual situation, the urban macro mode is suitable. In SCME model, a series of fixed power delay and angle parameters are often used to generate the channel model. The simulation process is simple and the channel matrix generates faster.

3.1. The principle of MIMO OTA channel modeling
As description of modeling the MPAC channel in the literature [4], for a NXM linear time-varying MIMO system consisting of N transmitting antennas and M receiving antennas, the transmission matrix between the output and the input can be described by impulse response in the theory of signal and system. The ray-tracing is selected to model the channel. Assuming that there are L roots in the identifiable path in the propagation environment, it has
\[ H(t, \tau) = \sum_{l} H_l(t, \tau) = \begin{bmatrix} h_{l1}(t, \tau) & h_{Nl}(t, \tau) \\ h_{Ml}(t, \tau) & h_{MNl}(t, \tau) \end{bmatrix} \]  

(1)

\[ H_l(t, \tau) = \int \int F_{\phi M}^T(\phi) h_l(t, \tau, \varphi, \phi) F_{\phi N}(\varphi) d\phi d\varphi \]

(2)

\[ h_l(t, \tau, \varphi, \phi) = \begin{bmatrix} a^V_l(t) \\ a^H_l(t) \\ a^{HV}_l(t) \\ a^{HV}_l(t) \end{bmatrix} \delta(\tau - \tau_l) \delta(\phi - \phi_l) \delta(\varphi - \varphi_l) \]

(3)

\[ H(t, \tau) \] represents the impulse response matrix of the l-th path between the transceivers, 

\[ (\varphi, \phi) \text{ and } F_{\phi M}(\phi) \] are the row vector of vector N and vector M, contains the gain information of the antenna array at the transmitter and receiver in the MIMO system. In other words, each element in 

\[ (\varphi, \phi) \text{ and } F_{\phi M}(\phi) \] represents the complex gain of each transmit and receive antenna element. This complex gain is a function of the angle and contains amplitude and phase information. \( \phi_l \) is the AoD of the l-th path, \( \phi_l \) is the AoA of the l-th path. \( (t, \tau, \varphi, \phi) \) contains the polarization conversion information of the l-th path in the propagation process.

The most important in the channel modeling of MIMO systems is to fully reflect the spread in the spatial domain during signal propagation. It will lead to changes in the spatial correlation between the multiple receiving antennas of the terminal, thus affecting system performance. In the SCME model, the TDL model is introduced. Each mid-path corresponds to different tap power and delay. Multiple sub-paths are superposed to form a mid-path. The mid-path can be close to the Rayleigh distribution. The mid-path can be simulated by classical Gaussian data generator.

3.2. SCME modeling process

Determining the environment

The environment of the MIMO OTA test is suitable for urban macro model in SCME.

Setting parameters

The number of BS terminals and MS terminals is set to 1 and 6. Set the direction of the direct path LOS with respect to BS and MS \( \theta_{BS} = \theta_{MS} = 0^\circ \).

Set the delay

In SCME model, we often use fixed power delay and angle parameters to generate a channel model. The delay can be obtained from the parameter configuration table of the channel environment, which is set by 3GPP.

The delays for the six main paths are set as \([0.3600 \ 0.2527 \ 1.0387 \ 2.7300 \ 4.5977]\) (us) in Table 2.

The delays for each mid-path can be calculated by \( \tau_{n,l} = \tau_n + \Delta_n, l \), \( \Delta n, l \) is the offset delay of the mid-path. \([0.0125 \ 0.025 \ 0.3600 \ 0.3725 \ 0.3850 \ 0.2527 \ 0.2652 \ 0.2777 \ 1.0387 \ 1.0512 \ 1.0637 \ 2.7300 \ 2.7425 \ 4.5977 \ 4.6102 \ 4.6227]\) (us).

Quantize the delay and get:

Determine the relative power \( P_{n,l} \) of each mid-path

Checking Table 2 to get the relative power \( P_{n} \) of each main path. According to the number of sub-path \((10, 6, 4)\) obtained in Table 1, the relative power of each medium diameter \( P_{n,l} \) is obtained, which is 1/2, 3/10, and 1/5 of the main path.

Making normalization depends on the Formula (4):

\[ P_n = \frac{P_{n,l}}{\sum_{j=1}^{6} P_{j}} \]

(4)
5. Determine the AoA for each sub-path 

\[ \theta_{n,m, AoA} = \theta_{MS} + \delta_{n, AoA} + \Delta n, m, AoA \]

Table 1. The parameters of the cluster in SCME (3GPP standard)

| Mid-path | Power (number of sub-path) | delay (us) in the main path | Sub-path |
|----------|----------------------------|----------------------------|----------|
| 1        | 10/20                      | 0                          | 1, 2, 3, 4, 5, 6, 7, 8, 19, 20 |
| 2        | 6/20                       | 0.0125                     | 9, 10, 11, 12, 17, 18 |
| 3        | 4/20                       | 0.025                      | 13, 14, 15, 16 |

Table 2. The parameters of urban macro

| Scenario | Power \( P_n \) and respect delay of each main path | Urban Macro |
|----------|---------------------------------------------------|-------------|
| 1        | 0                                                 | 0           |
| 2        | -2.2204                                           | 0.3600      |
| 3        | -1.7184                                           | 0.2527      |
| 4        | -5.1896                                           | 1.0387      |
| 5        | -9.0516                                           | 2.7300      |
| 6        | -12.5013                                          | 4.5977      |

| AS at BS and MS | AoA and AoD of each main path |
|-----------------|-------------------------------|
| 2               | 65.7489 81.9720 76.4750 -127.2788 |
| 2               | 45.6454 80.5354 -11.8704 -129.9678 |
| 3               | 143.1863 79.6210 -14.5707 -136.8071 |
| 4               | 32.5131 98.6319 17.7089 -96.2155 |
| 5               | -91.0551 102.1308 167.7657 -159.5999 |
| 6               | -19.1657 107.0643 139.0774 173.1860 |

4. Result analysis

In SCME, a series of fixed power delay and angle parameters are used to generate the channel model. The simulation process is simpler and the generation speed of channel matrix is faster. However, due to the influence of the mid-path, it takes up more memory. In the process of simulation, the SCME model is selected to model the channel.
Comparison of correlation for the first cluster of two algorithm under SCME model

The result is showed in figure 6. Correlation errors for the first cluster for the two algorithms are shown in the figure. The reference method is least square algorithm. The reference least square algorithm does not consider the angle, at the area $\Phi_a=30^\circ$ and $\Phi_a=210^\circ$, the performance is not well. The max deviation (0.024) in reference algorithm is bigger than that in proposed algorithm (0.018). Therefore, the proposed algorithm is better.

5. Conclusion
The paper made a complete design and implement of power allocation for probes in MIMO OTA tests. I finished the main tasks and targets following the schedule. The principle of MIMO OTA was introduced well. The mathematical model for power allocation was established. Spatial correlation was selected to model signal channel. The paper discusses the using of the PAS model, the concept of cluster and prefaded signal synthesis method. After that, paper proposed a formula to calculate the spatial correlation and rewrote the formula as a function of distance and relative position between virtual antennas. The innovation point of the project is introducing constraints on PAS shape in terms of AoA and AS, thus the problem can be converted into a convex problem.

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