FDM based MIMO Spatio-Temporal Channel Sounder

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Abstract

In this paper, implementation of Multi-Input Multi-Output (MIMO) channel sounder is considered, taking hardware cost and realtime measurement into account. MIMO sounder needs some kind of multiplexing to distinguish between transmitting antennas. We compared three types of multiplexing, i.e. TDM, FDM, and CDM, for the sounding purpose in terms of realtime measurement, hardware cost, and major drawbacks. Then we chose FDM based technique to achieve cost effectiveness and realtime measurement. In the framework of FDM, we proposed an algorithm to solve drawbacks and to estimate MIMO channel parameters. Furthermore the proposed algorithm was implemented into hardware, and validity of the proposed algorithm was evaluated through measurements in an anechoic chamber.

Keywords

channel sounder, MIMO, mobile propagation, channel parameter estimation, channel response matrix measurement, hardware implementation

INTRODUCTION

MIMO communication system is considered to be a key technology in the next generation mobile communication system. The reason is that the MIMO communication systems can increase the channel capacity without expanding the frequency bandwidth[1]. Since performance of the MIMO communication system depends on the directional as well as the temporal behavior of the channel, the field measurement data of MIMO channel are strongly required to develop and evaluate the MIMO communication systems.

The MIMO channel is considered to be parameterized by direction-of-arrival (DOA), direction-of-departure (DOD) and time-of-arrival (TOA). We can measure these parameters by using MIMO channel sounder.

An important difference between MIMO and conventional Single-Input Multi-Output (SIMO) channel sounding is that the MIMO sounder needs some kind of multiplexing to distinguish between transmitting antennas. We compared three types of multiplexing, TDM[2], FDM and CDM for the sounding purpose in terms of realtime measurement, hardware cost and major drawbacks. Then we chose FDM based technique to achieve cost effectiveness and realtime measurement. In the framework of FDM, we proposed an algorithm to estimate MIMO channel parameters. Furthermore the proposed algorithm was implemented into hardware and evaluated through measurement in an anechoic chamber.

MIMO CHANNEL PARAMETER ESTIMATION

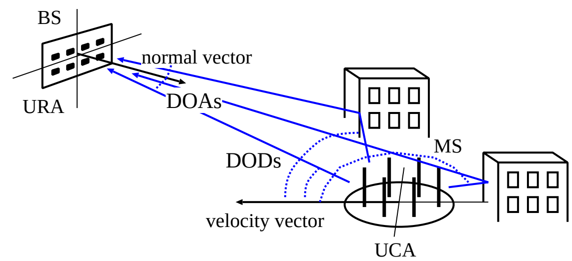

Figure 1. MIMO channel sounding environment

Consider an m_s-element transmitting array antenna at the mobile station MS(Tx), and an m_r-element receiving array antenna at the base station BS(Rx). The channel is considered to be a superposition of multipath components. Each path departs from the transmitting array with an azimuth angle θ_i^s and arrives at the receiving array with an azimuth angle θ_i^r, where i is an index of multipath components. Between Tx and Rx, each path has a delay time τ_i and a complex amplitude γ_i. A $m_r \times m_s$ channel matrix $\mathbf{H} \in C^{m_r \times m_s}$ at the center frequency of f_c can be expressed as

$$\mathbf{H} = \sum_i \gamma_i(t) e^{-j2\pi f_c \tau_i} \mathbf{a}_r(\theta_i^r)(\mathbf{a}_s(\theta_i^s))^T \qquad (1)$$

where $\mathbf{a}_s(\theta)$ and $\mathbf{a}_r(\theta)$ are transmitting and receiving array response vectors for the plane wave impinging from an azimuth angle θ. The channel matrix $\mathbf{H}$ can be reformulated to an $m_r \cdot m_s$ dimensional vector $\mathbf{h} \in C^{m_r \cdot m_s}$. Then, frequency response vector $\mathbf{a}_f(\tau)$ is introduced for the wideband measurement. Finally, the three dimensional channel response vector $\mathbf{h} \in C^{m_r \cdot m_s \cdot m_f}$ can be formulated as

$$\mathbf{h} = \sum_i \gamma_i \mathbf{a}_r(\theta_i^r) \otimes \mathbf{a}_s(\theta_i^s) \otimes \mathbf{a}_f(\tau_i) \qquad (2)$$

where $\otimes$ is Kronecker product. In this formulation, the MIMO channel parameters are DOA (θ_i^r), DOD (θ_i^s) and TOA (τ_i). This equation is in a simple form that can be easily extended to include elevation angle estimation.

We can consider Eq.(2) as multidimensional harmonic retrieval problem. Therefore the parameter sets $\{\theta_i^r, \theta_i^s, \tau_i\}$ can be simultaneously estimated by using multidimensional superresolution algorithms. In this paper, we employed 3-D Unitary ESPRIT [3][4] to estimate the above MIMO channel parameters with high resolution.

FDM BASED MIMO CHANNEL SOUNDING

The observable signal is only the superposition of contributions from all transmitting antennas in the MIMO system. Therefore some kind of multiplexing technique is needed to implementate the MIMO channel sounder.

By using an analogy with multi-user communication scenarios, three types of multiplexing techniques (TDM, CDM and FDM) are considered for sounding purpose in terms of realtime measurement, hardware cost, and major drawbacks as follows.

- TDM
  - Realtime measurement : poor
    Measurement which has $m_s$times baseband signal period and furthermore guard interval for excess delay and switching is needed.
  - Hardware cost : excellent
    Only one transmitter channel is needed.
  - Major drawback : Absolute time synchronization between transmitter and receiver is required.
- CDM
  - Realtime measurement : excellent
    Measurement period doesn't depend on m_s.
  - Hardware cost : poor
    It needs m_s transmitter channels.
  - Major drawback ; Dynamic range of the system is limited by m_s due to the cross-correlation between different codes.
- FDM
  - Realtime measurement : good
    Measurement period is m_s times baseband signal period.
  - Hardware cost : good
    It requires m_s local oscillators, but one baseband signal generator.
  - Major drawback : Some modification is needed for the data model, since the frequency sample points in each transmitting antenna are different.

As for the FDM technique, we introduced a new transmitting signal configuration as follows. In the case of m_s Tx antenna, firstly we prepare a multi-tone signal with tone separation of Δ_F. Then this signal and frequency shifted replicas are multiplexed in the frequency domain through the transmission from different antennas. The frequency shift Δ_f should be a fraction of Δ_F to keep an orthogonality between all of the tones. If Δ_f is small, we need long period for the Discrete Fourier Transfer (DFT) to separate multiplexed signals in the receiver side. The most efficient way for multiplexing is to set the frequency shift $\Delta_f = \Delta_F/m_s$. We call this technique as multi-tone FDM (MTFDM).

We successfully solved the drawback in FDM technique as follows. The newly introduced concept is a FDM response vector $\mathbf{a}_{\text{FDM}}(\tau_i) \in C^{m_s}$ defined as

$$\mathbf{a}_{\text{FDM}}(\tau_i) \triangleq [1, e^{-2\pi\Delta_f\tau_i}, \cdots, e^{-j2\pi(m_s-1)\Delta_f\tau_i}]^T \quad (3)$$

By using this vector, the transmitting array response vector

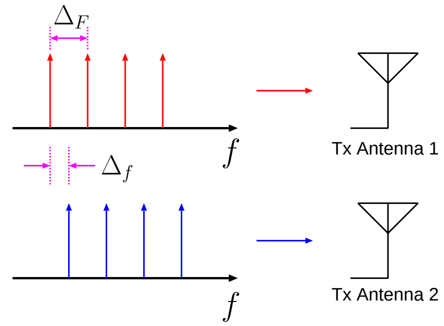

Figure 2. Multi-tone FDM for MIMO sounding

is rewritten as

$$\mathbf{a}'(\psi_i^s) = \mathbf{a}(\theta_i^s) \odot \mathbf{a}_{\text{FDM}}(\tau_i) \in C^{m_s} \quad (4)$$

where ψ_i^s is a function of θ_i^s and τ_i, and $\odot$ is Hadamard product. Finally the channel response vector for FDM based MIMO system is written as

$$\mathbf{h}' = \sum_i \gamma_i(t)\mathbf{a}_r(\theta_i^r) \otimes \mathbf{a}'_s(\psi_i^s) \otimes \mathbf{a}_f(\tau_i). \quad (5)$$

It is also considered as a harmonic, the parameter sets $\{\theta_i^r, \psi_i^r, \tau_i\}$ can be simultaneously estimated. Thus, the channel parameters can be estimated even by using the different frequency sample points in each transmitting antenna.

If the above solution is considered, there is no weakness in the FDM based technique, while at the same time, it can achieve both cost effectiveness and real time measurement. Therefore we choose this technique.

HARDWARE IMPLEMENTATION

We implemented the FDM based MIMO channel sounder. This is an extended version of the SIMO channel sounder which was proposed in [5]. To confirm the FDM based algorithm in a simple way, we employed 2-element linear patch array antenna both at Tx and Rx. Block diagrams of transmitter and receiver are shown in Fig.3 and Fig.4 respectively.

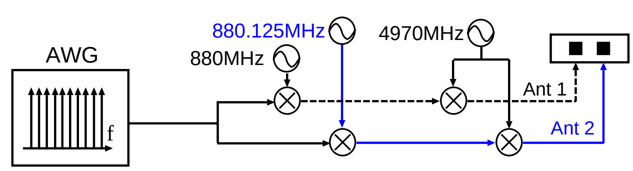

Figure 3. Transmitter block diagram.

Baseband multi-tone signal with tone separation of 500[kHz] is generated by using Arbitrary Waveform Generator (AWG). To implement the proposed MTFDM, two IF oscillators whose frequency are 880[MHz] and 880.125[MHz] were introduced. We employed a 125[kHz] frequency shift to avoid DC offset. Finally, these two signals are up-converted

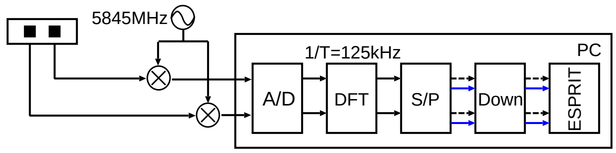

Figure 4. Receiver block diagram.

to 5.85[GHz] band and transmitted from each antenna. The spectrum of transmitting signals are shown in Fig.5.

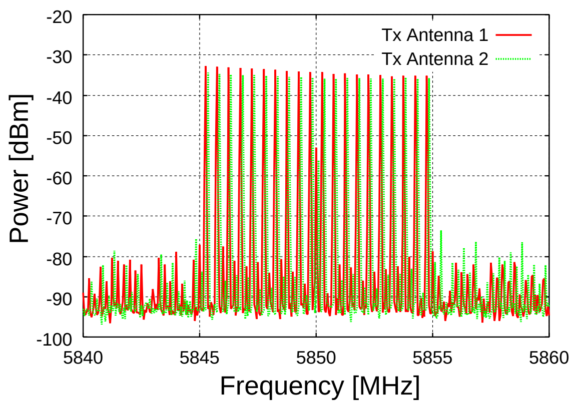

Figure 5. The spectrum of transmitting signals.

In the receiver side, we employed low-IF architecture, where IF = 5[MHz]. After down-converting to IF, the signals are sampled by A/D converter which operates at 20[Msps]. In the digital signal processor, DFT at a rate of 125[kHz] is performed to separate the multiplexed signals. Finally, we apply 3-D Unitary ESPRIT to the extracted signals to estimate the MIMO channel parameters.

MEASUREMENT EXAMPLE

Measurement experiment was conducted in an anechoic chamber to validate the FDM based algorithm and the FDM based hardware implemented. Measurement setup is illustrated in Fig.6. This situation is the simplest environment where there is only direct path. Both array antennas were located on the rotators which were rotated at 15[deg] intervals, Rx rotator angles : {-30, -15, 0, 15, 30 [deg]}, Tx rotator angles : {-15, 0, 15[deg]}, and measurements were conducted for all the pairs of angles. This measurement sequence was repeated 5 times to assure the repeatability. Back-to-back calibration was performed for hardware calibration.

Throughout the measurements, we took 30 snapshots, and the path gain to noise ratio was about 25[dB]. All of the measurement results with respect to the DOA and DOD are shown in Fig.7. If the estimated results are on the every 15[deg] grid, it indicates that a good performance in the measurement is achieved. From this figure, we could confirm the validity of the proposed algorithm and implemented hardware. The estimation error is mainly due to the set up and calibration

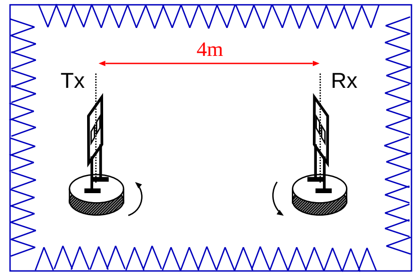

Figure 6. Measurement setup in the anechoic chamber.

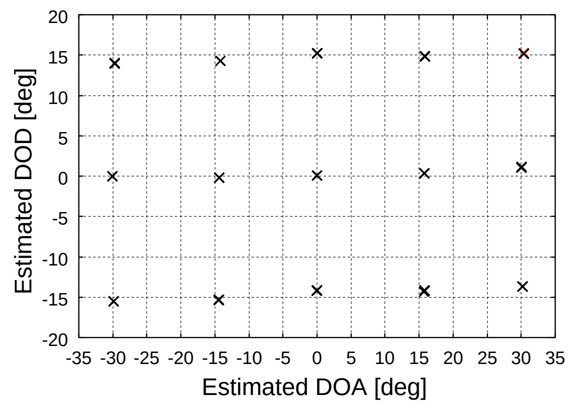

Figure 7. Experimental results in an anechoic chamber.

error during measurement.

CONCLUSION

MIMO channel sounding is an attractive way to measure the propagation mechanism in the mobile cellular environment. In this paper, an architecture for MIMO spatio-temporal channel sounder was thoroughly investigated. After considerable discussions about multiplexing techniques to distinguish between the transmitting antennas, the FDM based architecture was chosen to achieve cost effectiveness and realtime measurement. In the framework of FDM, we proposed a new transmitting signal configuration and a new algorithm to estimate the MIMO channel parameters, DOA, DOD and TOA simultaneously. We confirmed the validity of the FDM based architecture through the measurement in an anechoic chamber.

To achieve an efficient and practical MIMO spatio-temporal channel sounder, we need to optimize the MIMO array configuration and establish a novel calibration method for MIMO sounding system[7].

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