FDM based MIMO Spatio-Temporal Channel Sounder

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The performance of MIMO communication system depends on the directional as well as temporal behaviour of channel.

The field measurement data of MIMO channel are strongly required to develop and evaluate the MIMO communication systems.

An important difference between MIMO and SIMO channel sounding the MIMO channel sounder needs some kind of multiplexing to distinguish between transmitting antennas.
A $m_r \times m_s$ channel matrix $H$ at the center frequency of $f_c$ can be expressed as

$$H = \sum_i \gamma_i(t) e^{-j2\pi f_c \tau_i} a_r(\theta_{ri}) a_s(\theta_{si})^T$$

Frequency response vector is introduced for the wideband measurement.

The $m_r \times m_s \times m_f$ channel matrix $H$ can be reformulated to an $m_r \cdot m_s \cdot m_f$ dimensional vector $h$.

$$h = \sum_i \gamma_i a_r(\theta_{ri}) \otimes a_s(\theta_{si}) \otimes a_f(\tau_i) \quad \otimes : \text{Kronecker product}$$
By using an analogy with multi-user communication scenarios, we considered three types of multiplexing techniques for sounding purpose in terms of realtime measurement, hardware cost effectiveness, and major drawbacks.

The three types of multiplexing:

- TDM (Time Division Multiplexing)
- CDM (Code Division Multiplexing)
- FDM (Frequency Division Multiplexing)
TDM based Technique

- Realtime measurement ➔ poor
  Measurement which has ms times baseband signal period and furthermore guard interval and switching are needed.

- Hardware cost ➔ excellent
  It is realizable only by changing one transmitter to the other antennas with a switch.

- Major drawback
  Absolute time synchronization between transmitter and receiver is required.
CDM based Technique

- Realtime measurement → excellent
  Measurement period doesn’t depend on ms.

- Hardware cost → poor
  It needs ms transmitter channels.

- Major drawback
  Dynamic range of the system is limited by ms due to cross-correlation between different codes.
FDM based Technique

- Realtime measurement ➡ good
  Measurement period is $ms$ times baseband signal period.

- Hardware cost ➡ good
  It requires $ms$ local oscillators, but one signal generator.

- Major drawback
  Some modification is needed for the data model, since the frequency sample points in each transmitting antenna are different.
## Comparison of Multiplexing

<table>
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<tr>
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<th>Realtime Measurement</th>
<th>Hardware Cost</th>
<th>Major Drawback</th>
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<tbody>
<tr>
<td>TDM</td>
<td>poor</td>
<td>excellent</td>
<td>Synchronization between Tx and Rx</td>
</tr>
<tr>
<td>CDM</td>
<td>excellent</td>
<td>poor</td>
<td>Cross-correlation between codes</td>
</tr>
<tr>
<td>FDM</td>
<td>good</td>
<td>good</td>
<td>Frequency shift in Tx signals.</td>
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FDM achieve both realtime measurement and hardware cost effectiveness. Therefore, we chose the FDM based technique.
Multi-tone FDM

$$\Delta F$$

$$\Delta f = \frac{\Delta F}{m_s}$$

DFT

Rate: \(\Delta f\)

Rx Antenna

Multi-tone Signal

Tx Antenna 1

Tx Antenna 2
A FDM response vector is defined as
\[
a_{\text{FDM}}(\tau_i) \triangleq [1, e^{-2\pi \Delta f \tau_i}, \ldots, e^{-j2\pi (m_s-1)\Delta f \tau_i}]^T
\]

By using this vector, the transmitting array response vector is rewritten as
\[
a'(\psi^S_i) = a(\theta^R_i) \odot a_{\text{FDM}}(\tau_i) \quad \odot : \text{Hadamard product}
\]

Therefore, the channel response vector for FDM based MIMO system is written as
\[
h' = \sum_i \gamma_i(t) a_r(\theta^R_i) \otimes a'_s(\psi^S_i) \otimes a_f(\tau_i)
\]

By using this, the parameter sets \(\{\theta^R_i, \theta^S_i, \tau_i\}\) can be simultaneously estimated.
Hardware Implementation

Transmitter

Arbitrary Waveform Generator

880MHz
880.125MHz
4970MHz
5850MHz

Receiver

5845MHz

125kHz

A/D
DFT
S/P
Down Convert
ESPRIT
PC

Low IF : 5MHz
### Measurement Environment

- **Anechoic Chamber**
- **Distance**: 4m

<table>
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<tr>
<th>Tx antenna</th>
<th>2-element ULA</th>
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<tr>
<td>Rx antenna</td>
<td>2-element ULA</td>
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<table>
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<tr>
<th>Bandwidth</th>
<th>9.5MHz</th>
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<tr>
<td>$\Delta F$</td>
<td>500kHz</td>
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<tr>
<td>$\Delta f$</td>
<td>125kHz</td>
</tr>
</tbody>
</table>

- **Snapshot**: 30 times
- **SNR**: about 30dB
- **Estimation algorithm**: 3-D Unitary ESPRIT
Measurement Results

Tokyo Institute of Technology

Setting Value: the every 15[deg] grid

The factor of the main error:
- Setup error
- Calibration error
Conclusion

- 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 frame work of FDM, we proposed a new transmitting signal configuration and a new algorithm to estimate the MIMO channel parameters.

- We implemented the FDM based MIMO channel Sounder.

- We confirmed the validity of the FDM based architecture through measurements in anechoic chamber.