Channel Sounding Technique using MIMO Software Radio Architecture

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Outline

1. Introduction
   - Overview of MIMO channel sounding
   - Future perspectives of mobile communication Systems
   - Requirements for the desired sounder
2. Architecture
   - Hardware Architecture: Fully parallel MIMO sounder
   - Multiplexing Technique: FDM Multi-tone Sequence
3. Prototype
4. Calibration
   - Procedure and results
5. Test Measurements
   - Back-to-back Tests
   - Over the Air Tests

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Overview of MIMO channel sounding

Channel modeling ≈ Channel sounding
To simulate the behavior of real-world wireless channels

Channel parameters and their performances

- Temporal (delay resolution) ⇐ signal bandwidth
- Spatial (angular resolution) ⇐ waveform repetition rate
- Dynamic (doppler capability) ⇐ number of arrays

What do we want to measure?

The targeted system and its topology determine the requirements for the channel sounder.

Future perspectives of mobile communication Systems

Growing demand for higher data rates

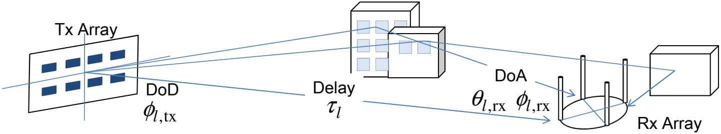
- Lack of wide frequency bands within the conventional spectrum
- MIMO is prerequisite but depends on the propagation channel
- Smaller cell coverage, so the reduction in MIMO independent paths
- Multi-link technologies (MU-MIMO, CoMP) will be necessary

Key words

High-frequency bands MIMO Multi-link topology

There have been quite some trial measurements, but there seem no sounding techniques and channel models presented from the above perspectives.

Requirements for the desired sounder



Simultaneous testing of transmission and propagation

- Same hardware both for the transmission tests and channel sounding
- Frame formats enabling the simultaneous tests

→ Real time analysis of the interrelation b/w trans. and prop.

Spatio-temporal channel behavior

- Level/delay: channel impulse response, delay spreads
- DoD/DoA: identification of propagation paths, angular spreads
- Doppler information for mobile applications

→ Further analysis of source of performance degradation, developments for the channel improvements technique

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Fully Parallel Sounder using Software Radio Architecture

Advantages

1. Simultaneous MIMO transmission and reception (Dynamic meas.)
2. 24×24 array (at final) (Directional properties)
3. Scalable arch. (4TRx×6units=24MIMO) (Multi-link meas.)

Issues

Hardware costs, complicated calibration process

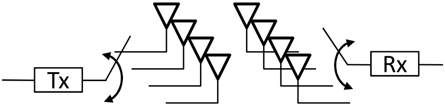


Figure: Switching MIMO sounder with multiplexer (conventional)

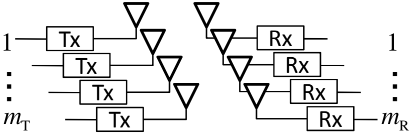
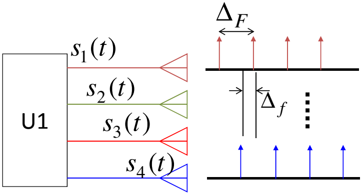


Figure: Fully parallel MIMO sounder using software radio architecture

FDM Multi-tone for Wideband Channel Excitation

$$\boldsymbol{s}_n(t) = \frac{1}{\sqrt{N_{\mathrm{FFT}}}} \sum_{n=0}^{N_{\mathrm{FFT}}-1} e^{j2\pi\cdot\Delta_F t+\varphi(n)} \begin{bmatrix} 1 \\ e^{j2\pi\cdot\Delta_f t} \\ e^{j2\pi\cdot 2\Delta_f t} \\ e^{j2\pi\cdot 3\Delta_f t} \end{bmatrix}$$

$\varphi(n) = \frac{\pi n^2}{N}$: Newman phase condition[1]



Frequency Division Multiplexing (FDM)

Specifications

Center frequency	11GHz
Signal Bandwidth	400MHz
FFT number $\Longrightarrow N_{\mathrm{FFT}}$	4096
Num. of subcarriers N	2048
Subcarrier spacing Δ_F	195.3KHz
FDM offset $\Delta_f = \Delta_F/4$	48.8KHz

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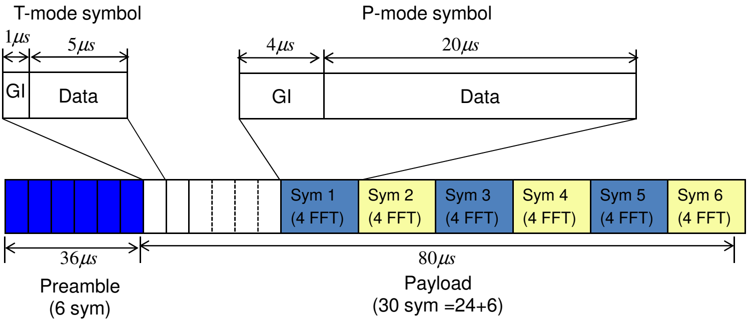
[1] S. Boyd, "Multitone signals with low crest factor," IEEE Trans. on Circuits and Systems, 1986.

Frame Formats combining Trans. and Prop. Symbols

- Expected max. delay through the channel ($4\mu s$)
- Max. doppler frequency (10km/h mobile scenario)
- Transmission efficiency to achieve 10Gbps



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Prototype 4×4 MIMO-SR Sounder

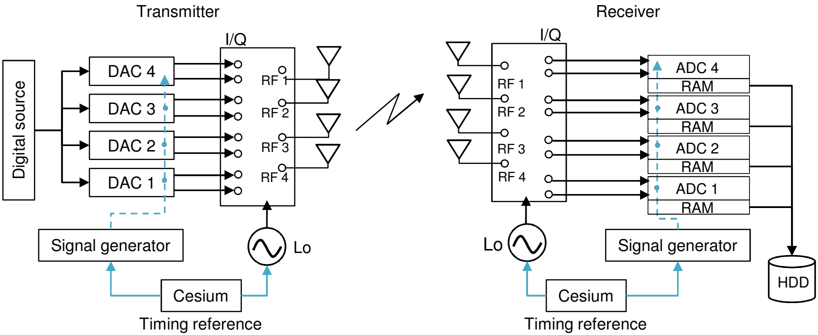

Figure: Block diagram of prototype 4×4 MIMO-SR sounder

Prototype 4×4 MIMO-SR Sounder

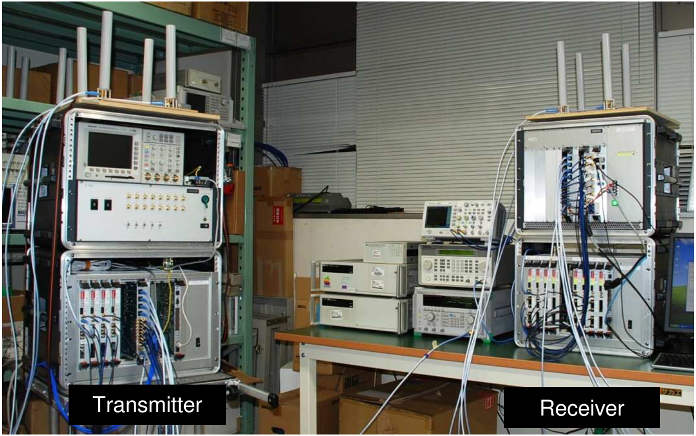

Figure: Prototype 4×4 MIMO-SR sounder

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Calibration Procedure

Step1) Baseband: Matching all the channels of DACs and ADCs

Following are manually adjusted by on-board variable registers.

1. Phase and DC offsets of DACs [DAC → Osc.]
2. Phase and DC offsets of ADCs [DAC → ADC]

Step2) RF: IQ imbalance compensation

1. Tx: Manual suppression of carrier leak and image with spectrum analyzer [DAC → Tx → SA]
2. Rx: Compute Rx imbalance compensation parameters [DAC → Tx → Rx → ADC]

Step3) Measure the system transfer function $\mathrm{H}_{\mathrm{cal}}$

Obtain 4×4 calibration matrix using calibration kit
[DAC → Tx → CalKit → Rx → ADC]

Calibration Results: Baseband

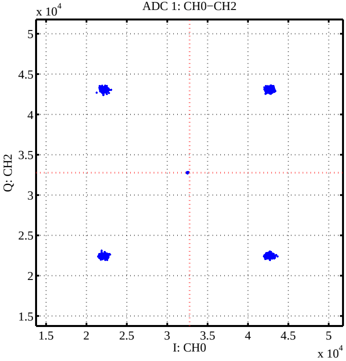


Figure: IQ const. of received signal

Accuracy of baseband calibration is confirmed by measureing EVM

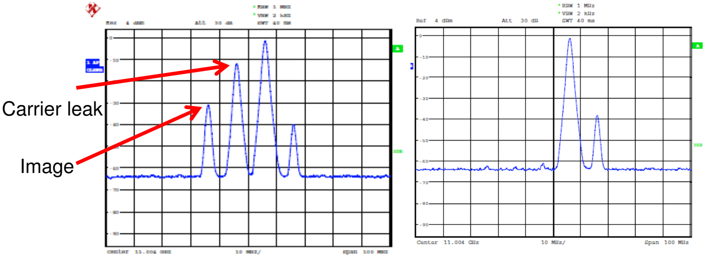
Modulation	EVM [%]
QPSK (r=1/2)	≈ 1.5

RF IQ Imbalance Comp. Results

Improvements of EVM are clear by applying IQ imbalance compensation

Table: Average EVM [%]: Tx1-Rx1

Lo signal	Shared				Individual(Rubidium)			
Compensation	both	at Tx	at Rx	nor	both	at Tx	at Rx	nor
QPSK	4.76	9.41	6.14	6.32	9.28	11.63	10.07	13.72



Before

After

RF IQ Imbalance Comp. Results

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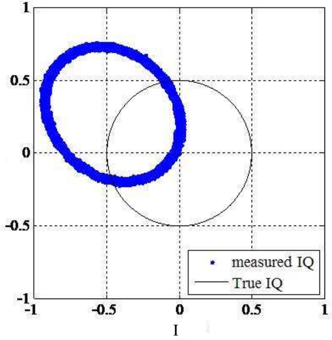
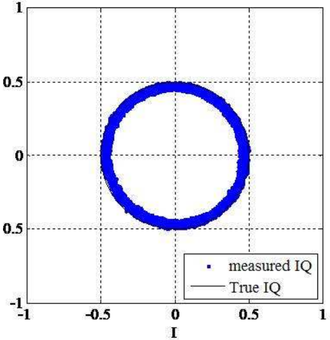


Before



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Back to back SISO Tests: Setup

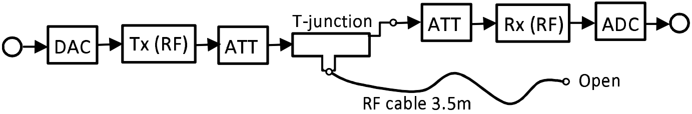


Figure: Back to back test using T-junction

Back to back tests were performed to check the basic property of the prototype sounder as follows.

1. Hardware test: Channel simulator circuit using T-junction
   The channel response of the T-junction with RF cable is priory measured by the vector network analyzer (VNA) as a reference.
2. Software test: Fading process added at transmitter
   Fading process are generated by the software (16 paths, exponential decay model) and added at the transmitter.

Back to back SISO Tests: Results

The results confirmed the basic performance of the sounder hardware and the calibration accuracy.

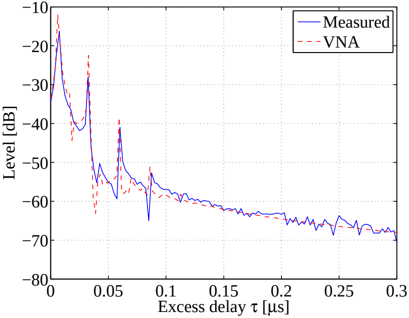


Figure: Channel impulse response for Hardware test

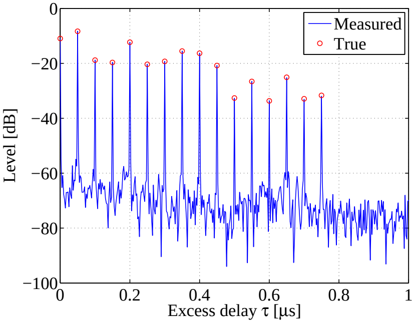
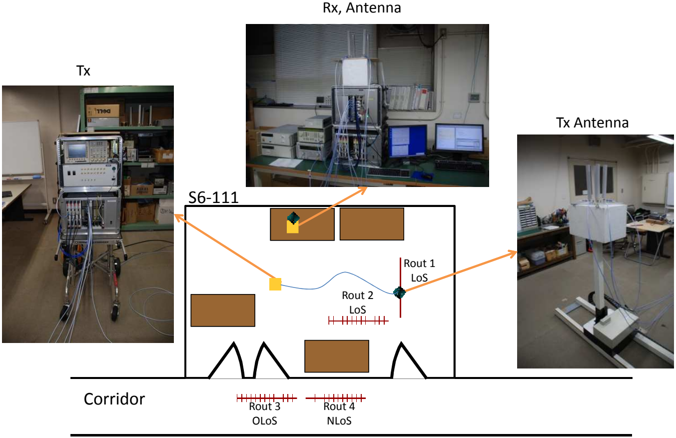


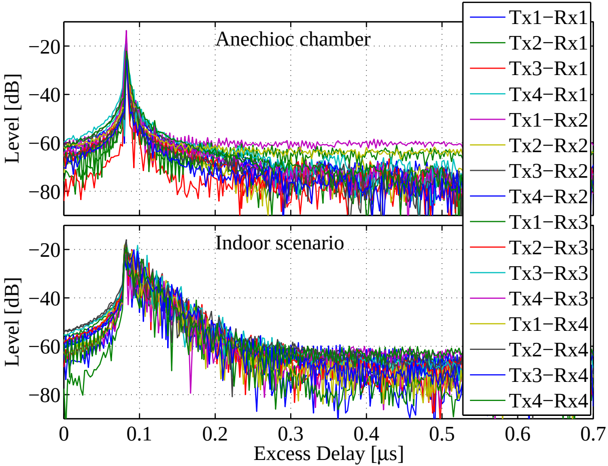
Figure: Channel impulse response for Software test

Over the Air Test: Indoor Environment



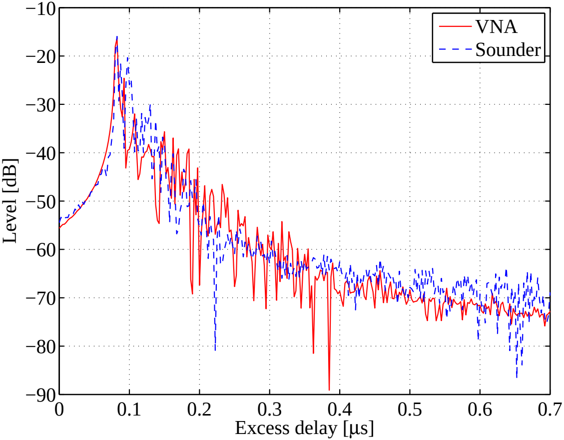
Over the Air Test: Indoor and Anechoic chamber

4×4 MIMO measurement was performed with vertically polarized circular array in an anechoic chamber and indoor scenario.



Over the Air Test: VNA and Prototype Sounder

VNA is used to measure the CIR in an indoor scenario.
Observed delay spreads and decay characteristics by VNA and sounder are found as almost similar.



Conclusion and Future Works

Conclusions

1. MIMO sounding technique using software radio architecture is proposed
2. 4×4 MIMO-SR sounder is developed as a prototype
3. Back to back and over the air test measruements validated the preliminary performance of the protopype sounder

Future Works

1. Preparation for the field measurement at Ishigaki-jima
2. Improvements of calibration technique

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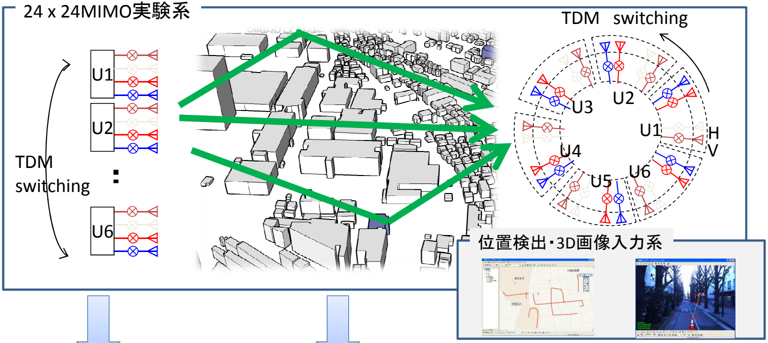
2. The original source code for the operation and technical know-how of presented results are supported by Suzuki-Fukawa Laboratory.

Thank you for listening.

Final



伝送特性

実伝搬路における
スループット

同期

伝搬路特性

- 遅延特性
- 放射・到来方向
- ドップラ特性

同期

測定環境の情報

- GPS位置情報
- 周囲の3次元画像情報