DEVELOPMENT OF MICROWAVE BROADBAND FULL-MIMO CHANNEL SOUNDER

For the Super High Bit-Rate Mobile Communication Systems

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Abstract: The paper summarizes four year activities and outcomes of development of full MIMO 24x24 channel sounder operating at 11 GHz with the bandwidth of 400 MHz, for the development of microwave frequency for the super high bit-rate mobile communications. The back ground motivation, design criteria, technical challenges and significant results are presented. Since the development of the channel sounder was the project goal, the detailed analyses of the double directional channels are left for future study.

1 INTRODUCTION

The rapid growth of the mobile data traffic demands the super high bit-rate systems in near future, i.e. more than 10 Gb/s/base station (BS). To realize such a high bit-rate transmission, the bandwidth well exceeding 100 MHz is required. Suzuki, Suyama and Fukawa (2010) estimated that 24x24 MIMO transmission with 400 MHz bandwidth can achieve 30 Gb/s/BS by deploying 64QAM and coding rate of 3/4 with overhead efficiency of 70%. Such wide bandwidth is not at all available below 6 GHz, which is believed to be the upper frequency limit for the mobile or personal wireless access. Therefore, the development of higher microwave frequency for the mobile communications is crucial. Such high frequency has been avoided for the mobile communications, because of the strong shadowing and large path loss. However, hybrid spectrum techniques such as carrier aggregation or separation of control and traffic channels have been recognized as promising techniques to resolve the problem. Low frequency narrowband channel is used to keep the link for control and base traffic, while high frequency wideband channel is opportunistically used for high bit-rate traffic.

NTT Docomo, Tohoku University and Tokyo Institute of Technology conducted the research project on super high-bit rate mobile communication systems for 4 years from 2009 until 2013 targetting 30 Gb/s/BS transmission. 11 GHz has been identified due to the availability of the spectrum for the test license with the bandwidth of 400 MHz. In collaboration with the transmission technology team, the authors have developed 24x24 channel sounder with full MIMO software radio architecture.

The paper summarizes the design criteria, technical challenges, and the outcomes in the development of MIMO channel sounder.

2 DESIGN CRITERIA AND TECHNICAL CHALLENGES

Full MIMO architecture is chosen for sharing the limited hardware resources for channel sounding and transmission test. The typical MIMO channel sounders are implemented with SISO RF chain with antenna multiplexers (e.g. MEDAV, n.a.). They have the advantages of the cost and simplicity of calibration. However, full MIMO architecture has an obvious advantage of the flexibility of multilink measurement by introducing the modular architecture. In contrast, simple combination of MIMO channel sounders is not so straightforward for the practical measurements (Kolmonen et al., 2010).

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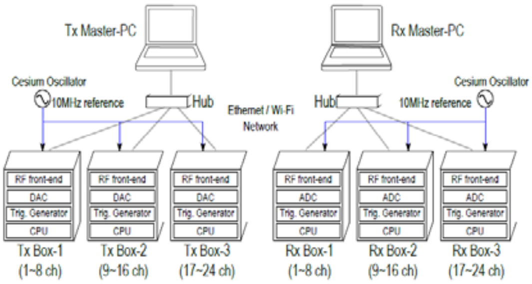
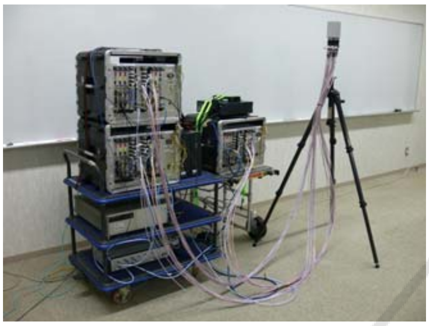


Figure 1: Scalable full MIMO channel sounder architecture.



(a) Receiver

(b) Transmitter

Figure 2: MIMO channel sounder.

2.1 Synchronization

In the developed channel sounder, one transmitter or receiver module consists of 8 RF channels, and three modules can be integrated for directional measurement, or be separated for multilink MIMO measurement. They are synchronized by the common or separated atomic oscillators. It is noted that the absolute synchronization of frequency and phase between transmitters and receivers is a specific requirement for channel sounder, although the hardware architectures are common for sounding and transmission. It is found that rubidium oscillators, which are commonly used as 10 MHz references for synchronization between transmitter and receiver, can not be stable enough when up-converted to 11 GHz. Therefore, the cesium oscillators are used instead. In addition to the frequency synchronization, the clock phase synchronization is necessary. The mechanism is implemented to adjust the clock phases of transmitter and receiver during back-to-back calibration between transmitter and t receiver.

2.2 Signal Format

Due to the simultaneous transmission, multiplexing technology is needed. Although any kind of orthogonal signals can be used for multiplexing, the authors chose unmodulated multitone signals and hybrid FDM-STDM technique suitable for scalable modular structure (Kim, Takada and Konishi, 2012).

Newman phase multitone (Boyd, 1986), which is almost equivalent to chirp signal, has been used as the wideband signal. Multitone signal has the advantage of efficient spectrum usage for high delay resolution. 4 channels are multiplexed in frequency domain (FDM) (Sakaguchi, Takada and Araki, 2002), i.e. 1 module consists of 2 units. 6 units, each of which consists of these 4 channels, are then weighed with orthonormal vectors sequentially to change the spatial pattern of the channel response (STDM). STDM has the obvious advantage over conventional TDM, since all the transmitter ports always transmit the signals to maximize the transmission power by using relatively low power transmitters.

2.3 Antennas

Three types of array antennas are developed.

Directional measurement antenna is a uniform circular array of 12-element dual polarization antennas with 0.44 wavelength spacing. For the high resolution parameter estimation, spherical complex pattern has been measured discretely within the limited range of the scanning, and the continuous patterns for whole sphere are analytically reconstructed by using the spherical wave functions (Miao and Takada, 2013).

Two MIMO capacity measurement antennas are both uniform linear arrays of 12-element dual polarization antennas. Two different types of the antenna elements are used, i.e. omnidirectional and 60 deg sector patterns in horizontal direction.

Antenna spacing can be flexibly controlled, but should be more than one wavelength due to the large size of the horizontal polarization antenna elements.

2.4 Calibration Procedure

To calibrate the whole MIMO system, the following complicated calibration process is needed whenever the units are turned on (Chang, Konishi, Kim and Takada, 2012):

1. Baseband calibration to match all the channels of DACs and ADCs (Pham, Kim and Takada, 2012)
   Following calibration processes are manually conducted by adjusting on-board variable registers of delay chips, as the calibration parameters do not change for long time.
   (a) Phase and DC offsets of DACs are calibrated by connecting DAC to oscilloscope.
   (b) Phase and DC offsets of ADCs are calibrated by connecting ADC to DAC.
2. RF calibration to compensate IQ imbalance and to suppress carrier leakage (Kim, Konishi, Takada and Gao, 2012, Kim, Maruichi and Takada, 2013)
   As PLL synthesizers are reset whenever the power is turned on, the automatic calibration program has been developed.
   (a) Transmitter IQ imbalance and carrier leakage are compensated by digital predistortion.
   (b) They are calibrated by connecting DAC to Tx input and spectrum analyzer to Tx output. IQ imbalance is calibrated first, and carrier leakage next.
   (c) Receiver IQ imbalance and carrier leakage are calibrated in digital domain by connecting whole baseband and RF chain.
3. Back-to-back calibration for transfer function (Chang, Konishi, Kim and Takada, 2012)
   (a) 8x8 calibration circuit has been developed for module-wise back-to-back calibration. 1 out of 8 transmitter ports is selected by RF switch for feeding, while 8-port power divider feed all 8 receiver ports simultaneously. For 24x24 calibration, reference pair of transmitter and receiver modules are selected, and other modules are calibrated against these modules. S-parameters of calibration circuit itself are compensated finally.

3 SPECIFICATION OF CHANNEL SOUNDER

The channel sounder is originally designed to operate in macrocellular and indoor environment (Konishi, Kim, Chang and Takada, 2013).

The channel sounder is operating at the center frequency of 11 GHz with the bandwidth of 400 MHz. Output power of the transmitter is 10 dBm per channel, and the total transmission power is about 24 dBm with 24 transmitter ports.

Special frame format is introduced to transmit the sounding signal and the data stream simultaneously, 4 μs guard interval is inserted into each FDM symbol, which limits the maximum delay spread although 2048 tones are introduced within 400 MHz band. The delay resolution of 2.5 ns is determined from the bandwidth of 400 MHz.

Measurement dynamic range is 55~110 dB in terms of path loss, and the noise floor is dominated by the thermal noise.

Angular resolution of uniform circular array is about 37 degrees. However, ray optical propagation model and maximum likelihood parameter estimation technique (Fleury et al., 1999) are being introduced to de-embed the antenna characteristics from measured propagation channel.

4 FIELD MEASUREMENT CAMPAIGN

Measurement campaign has already been conducted in indoor, microcell and macrocell environments, since the radio license was valid only during the project period.

4.1 Indoor Measurements

Indoor measurements were conducted in the corridor, meeting and lecture rooms, entrance lobby, and hall within the campus of Tokyo Institute of Technology. Point crowds of the interior of the rooms were simultaneously measured by using laser scanner, together with the fish eye images, so that the propagation mechanism can be analyzed in more detail.

Although the detailed data analyses are left for future works, some preliminary works such as multi-link channel characteristics in the hall (Konishi et al., 2012), and path loss and delay spread of corridor-to-room channel (Kim, Konishi, Chang and Takada, 2013) are presented.

4.2 Outdoor Measurements

Outdoor measurements are conducted in macrocell and street microcell environments, within Ishigaki city, Okinawa. Ishigaki city is located in rather remote island, and is populated with about 50,000 people. Measurements were done in urban and residential areas.

Point crowds of the surfaces of the buildings were simultaneously measured by using laser scanner, as well as 3D image (Topcon, n.d.).

Although the detailed analyses are left for future works, some preliminary works such as macrocell line-of-sight path loss (Chang et al., 2013a) and MIMO eigenvalues (Chang et al., 2013b) are presented.

4 CONCLUSIONS

The paper presented the design criteria, technical challenges, and the outcomes in the development of 24x24 full MIMO channel sounder operating at 11 GHz with 400 MHz bandwidth for the development of future super high-bit rate mobile communications. The development of the channel sounder itself was quite successful, while the detailed analysis of the measurement campaigns is still left for the future work.

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