Performance Comparison of MIMO Channel Sounder Architecture in Between TDM scheme and FDM scheme

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Abstract— **A conventional channel sounder for measuring MIMO radio channel is based on Time Division Multiplexing(TDM) using Pseudo-Random Binary Sequence(PRBS) as a pilot sequence and can measure the MIMO channel accurately in slow fading environment. However this sounder has a big drawback that the accuracy of channel measurement is degraded largely in fast fading environment. To overcome this limitation, channel sounding architecture based on Frequency Division Multiplexing(FDM)[1] has already proposed, but the performance comparison between novel FDM scheme and conventional TDM scheme was not presented. In this paper, channel sounding performance between conventional TDM scheme and proposed FDM scheme is compared by mean square error(MSE) and angular spread error(ASE) through simulation. As a result, it is shown that the FDM sounding architecture measures MIMO channel more accurately than TDM sounding architecture with regard to MSE and ASE.**

Keywords-component; MIMO Channel Sounder, TDM, FDM, Mean Square Error, Angular Spread Error

I. INTRODUCTION

It is anticipated that MIMO systems will play an important role in increasing spectrum efficiency and link reliability in the next generation wireless communication systems. And because MIMO wireless channel has spatially directional property unlike SISO channel, accurate field measurement of MIMO channel is required for analyzing MIMO channel and evaluating MIMO communication systems.[2]

A big difference between SIMO(Single Input Multiple Output) channel sounder and MIMO channel sounder is that MIMO channel sounder needs a multiplexing technique to separate signals from all Tx antennas. A conventional MIMO channel sounder used in commercial product is based on time division multiplexing(TDM) and uses pseudo random binary sequence(PRBS) as sounding signals.[3,4] This TDM-based channel sounder measures MIMO channel well in slow fading environment, but it has difficulty in measuring fast fading channel because of the characteristic of TDM architecture that sounding signals from each Tx antenna are transmitted periodically in proportion to the number of Tx antennas. This TDM-based sounder also has some other drawbacks caused by TDM architecture such as precise synchronization in every time slot and accuracy reduction during switching time. And it is considered that these things will obstruct the MIMO channel measurement for the next generation wireless communications.

For this reason, frequency division multiplexing (FDM)-based MIMO channel sounding architecture is proposed in [1] as an alternative scheme of TDM architecture. But we don't know whether FDM architecture in MIMO channel sounder measures better than TDM architecture because the specific performance comparison between TDM and FDM scheme is not presented in [1].

In this paper, we proposed an efficient FDM based-MIMO channel sounder architecture, implemented it in simulation, and compared its measurement performance with that of TDM architecture. Assuming that 3GPP/3GPP2 SCME(Spatial Channel Model Extended) is real channel, mean square error(MSE) and angular spread error(ASE) between real channel and estimated channel are used as measurement parameters for the performance comparison. MSE is evaluated in 4x4 MIMO channel environment and ASE is calculated in 4x8 MIMO channel environment by using smooth ESPRIT algorithm for DOA(Direction of Arrival) estimation.[5]

This paper is organized as follows. It starts with understanding of TDM sounder architecture in section II. In section III, our proposed FDM sounder architecture is introduced. In section IV, the simulation environments are shown, and performance comparison between TDM and FDM architecture is presented through simulation results. Finally the conclusion is discussed in section V.

II. TDM-BASED MIMO CHANNEL SOUNDER

TDM architecture of MIMO channel sounder uses a switch to connect one RF module with all antennas in each transmit and receive platform and utilizes PRBS as sounding signals as shown in Fig. 1. Although the use of only one RF module is cost-effective some crucial problems which hinder more precise channel measurement exist and are introduced in section I. Especially, periodic transmission structure of signals from each Tx antenna in Fig. 2 makes it hard for signals in

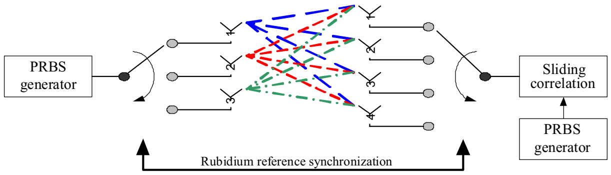

Figure 1. TDM architecture of MIMO channel sounder

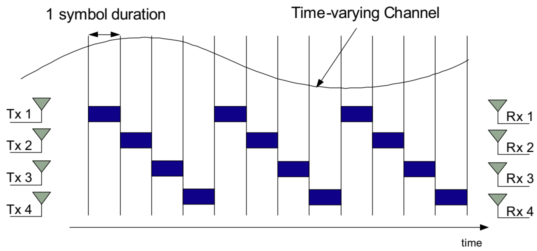

Figure 2. TDM-based signal transmission in time-varying channel

each Tx antenna to go through the same channel in fast fading channel environment. Because signals from all Tx antennas have to experience a temporal channel concurrently for the accurate measurement of MIMO spatial channel, the accuracy of MIMO channel sounding with TDM architecture is decreased in case that the time-variation of channel is larger or the number of Tx and Rx antennas increases.

To estimate the channel from the received signals the following correlation method is used.[6] When pseudo random binary signal $\mathbf{x}$ is transmitted, received data $\mathbf{y}$ is expressed as

$$\mathbf{y} = \mathbf{x} * \mathbf{h} + \mathbf{n} \tag{1}$$

where $\mathbf{h}$ is impulse response of the channel and $\mathbf{n}$ is white noise from receiver. We can rewrite (1) using circular matrix $\mathbf{X}$ as

$$\mathbf{y} = \mathbf{X}^H \cdot \mathbf{h} + \mathbf{n} \tag{2}$$

where

$$\mathbf{X} = \begin{bmatrix} x(0) & x(1) & x(2) & \cdots & x(N-1) \\ x(N-1) & x(0) & x(1) & \cdots & x(N-2) \\ x(N-2) & x(N-1) & x(0) & \cdots & x(N-3) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x(1) & x(2) & x(3) & \cdots & x(0) \end{bmatrix}$$

$$\mathbf{h} = [h(0) \quad h(1) \quad \cdots \quad h(N-1)]^T \tag{3}$$

$$\mathbf{n} = [n(0) \quad n(1) \quad \cdots \quad n(N-1)]^T$$

Let L be the length of PRBS $\mathbf{x}$, then the estimated channel $\hat{\mathbf{h}}$ can be obtained through following (4).

$$\hat{\mathbf{h}} = \mathbf{X} \cdot \mathbf{y} / L \tag{4}$$

III. FDM-BASED MIMO CHANNEL SOUNDER

MIMO channel sounder with FDM architecture enables all Tx antennas to transmit signals concurrently by allocating subcarriers that are orthogonal among them in frequency domain into each Tx antenna utilizing multiple carriers. When the total number of subcarriers is N and the number of Tx antennas is M, the number of the allocated subcarriers per each Tx antenna are N/M and arranged as shown in Fig. 3.[7]

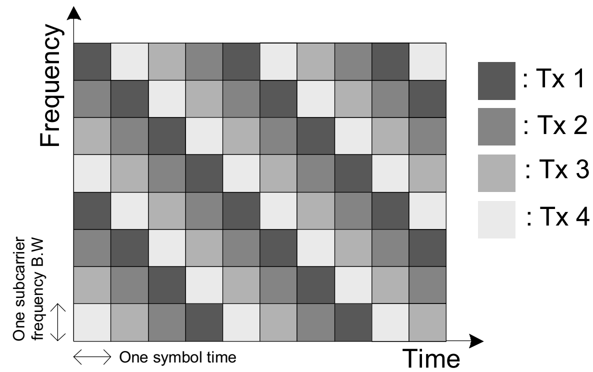

Figure 3. Subcarrier allocation when N=8, M=4

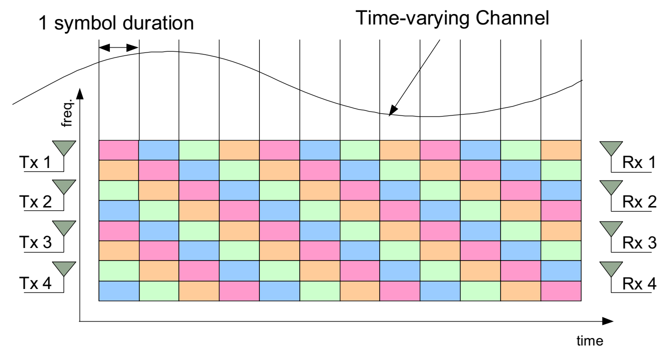

Figure 4. FDM-based signal transmission in time-varying channel

This subcarrier allocation method which is proposed in [7] as a combination of comb type[8] and block type[9] pilot allocation in OFDM systems has a big advantage that it can measure all Tx signals simultaneously and all frequency areas by applying some interpolation methods in time domain as shown in Fig. 4. The method to estimate the channel is as follows. When signal X generated in frequency domain is transmitted, received data is represented in time domain as

$$\mathbf{y} = IFFT(\mathrm{X}) * \mathbf{h} + \mathbf{n} \tag{5}$$

where $\mathbf{h}$ is impulse response of the channel and n is white noise from receiver. This equation is also transformed by using fast fourier transform as

$$\mathbf{Y} = \mathbf{X} \cdot \mathbf{H} + \tilde{\mathbf{n}} \tag{6}$$

Where $\mathbf{X} = diag(\mathbf{x}(0), \mathbf{x}(1), \ldots, \mathbf{x}(N-1))$, $\mathbf{H} = FFT(\mathbf{h})$ and $\tilde{\mathbf{n}} = FFT(\mathbf{n})$. And by using received signal $\mathbf{Y}$ and known transmitted signal $\mathbf{X}$, we can estimate the channel in frequency domain as follows.

$$\hat{\mathbf{H}} = \mathbf{X}^H \cdot \mathbf{Y} \tag{7}$$

Finally by changing (7) into time domain by using IFFT(inverse FFT), we can obtain the channel in time domain.

$$\hat{\mathbf{h}} = IFFT(\hat{\mathbf{H}}) \tag{8}$$

IV. SIMULATIONS

A. Designs

Assuming the channel generated from SCME is real channel, the measured channel is estimated from signals which passed through SCME by TDM or FDM based MIMO channel sounder. And then, MSE and ASE is calculated from SCME and measured channel data. In the end we can verify which multiplexing architecture is better by comparing MSE and ASE of TDM and FDM scheme.

B. Environments

It is settled that the center frequency is 5.3 GHz, the bandwidth of the channel is 100MHz(chip resolution is 10ns) and mobility environment is from 0 km/h up to 120 km/h. And because SCME makes 24 subpaths, channel measurement means finding these all 24 subpaths in frequency-selective channel. To decide the length of PRBS, we have to know the coherence time. Because maximum moving velocity is 120 km/h, maximum doppler frequency is obtained like $f_{D\max} = f_c \cdot v / c = 5.3\text{x}10^9 \text{x}120/3.6/(3\text{x}10^8) = 589\ \text{Hz}$. Assuming coherent time is the time duration when the correlation between signals is 0.99, the coherence time is obtained as

$$T_{coh} \approx 1/(100 \cdot f_{D\max}) = 1/(100 \cdot 589) = 17\mu s \tag{9}$$

Then maximum length of PRBS is $17\mu s / 10\ \text{ns}{=}1700\ \text{chips}$. But because the length of PRBS has the form of $2^n - 1$ (n is natural number), 1023 chips which are lower than and close to 1700 chips is finally chosen. MSE is experimented in 4x4 MIMO channel environment and ASE is calculated in 4x8 environment by using smooth ESPRIT algorithm.

C. Results

Fig. 6 and Fig. 7 are the results of MSE calculation in 0 km/h and 120 km/h moving environment. In Fig. 6, we can confirm that MSE of FDM scheme has 9 dB lower than that of TDM scheme in slow fading regardless the ratio of signals to noise. We can estimate that this is because the autocorrelation of PRBS is not perfect. Because the side lobe value of PRBS is not zero but $1/(2^n\text{-}1)$, the cumulated side lobe interferences of PRBS from 24 subpaths increases MSE.

In Fig. 7, it is verified that in fast fading environment the performance of TDM scheme is not good and FDM scheme can be the alternative scheme instead of TDM. In channel sounding, because SNR is usually high enough to measure channel accurately we need to concentrate on the high SNR of x axis in Fig. 7.

Fig. 8 presents the graphs of RMS ASE in each probability to calculate the accuracy of measurement. In the result, we can see that ASE of SCME that is assumed to be a real channel in this experiment is the lowest and FDM is the next and TDM has the highest ASE. Like MSE case, consequently, the accuracy of angular spread measurement in FDM architecture is better than in TDM architecture.

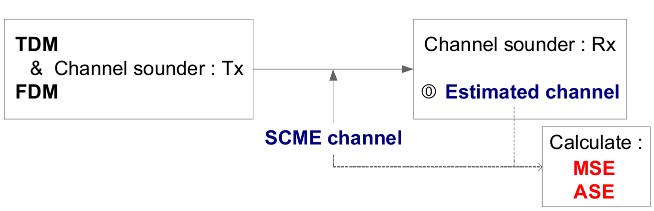

Figure 5. Design of simulation process

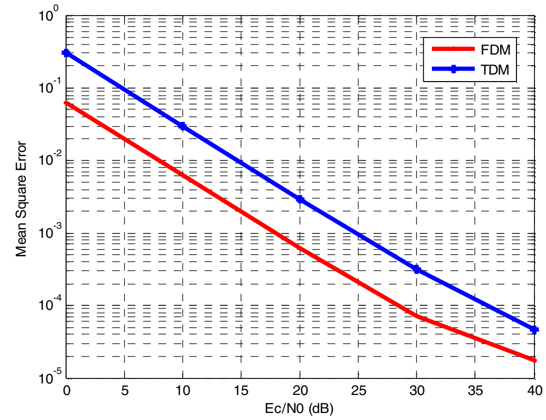

Figure 6. MSE comparison in 0 km/h

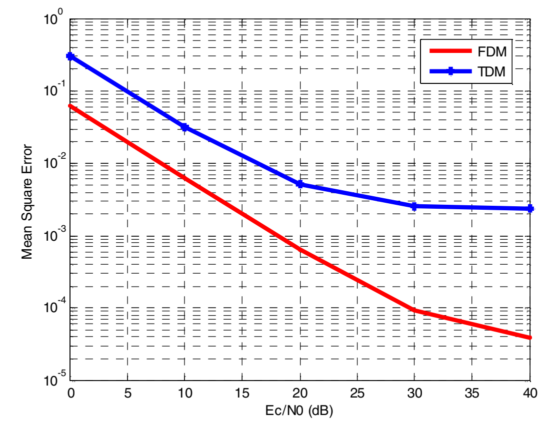

Figure 7. MSE comparison in 120 km/h

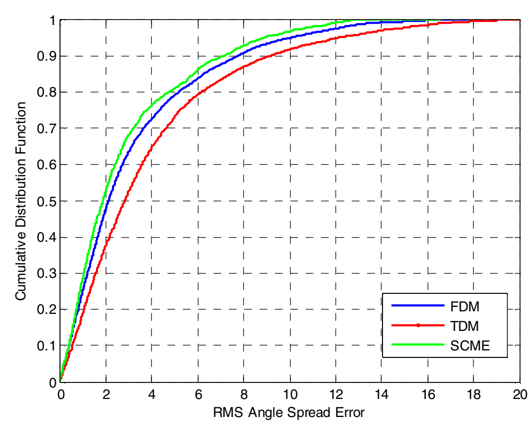

Figure 8. ASE comparison in 120 km/h, Ec/No=40 dB

V. CONCLUSIONS

In this paper, we proposed an efficient FDM-based MIMO channel sounding scheme and compared the performance of channel measurement between FDM architecture and TDM architecture through simulations using SCME. Through the results of MSE and ASE measurement, we can conclude that FDM scheme measures MIMO channel better than TDM scheme and especially the larger the time variation of channel is, the larger the difference of the performance between them is in fast fading channel environment as estimated.

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