A Study on a Novel Transmit Scheme for MIMO Channel Sounding Architecture

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***Abstract*— Code division multiplexing(CDM) based MIMO channel sounder architecture is excellent at measuring fast fading channel. In this paper, Loosely Synchronous(LS), Kasami and Chaotic sequences are suggested as candidates for the code that will be used in CDM architecture. Among those sequences, then, the best suitable sequence for channel sounding is examined through simulation. And by proposing the combined scheme of CDM and TDM when the number of transmit antennas are more than 4, the decrease of dynamic range due to interferences between different sequences can be mitigated.**

I. INTRODUCTION

It is anticipated that MIMO wireless access technology will play an important role in increasing spectrum efficiency and link reliability in the next generation wireless communication systems.[1] In MIMO systems, the radio channel has spatially directional property as well as temporal property unlike SISO channel. Therefore an accurate knowledge about MIMO channel is largely required for developing MIMO communication systems and this necessitates the accurate measurement of MIMO wireless channel. In the concrete, the measurement data can be utilized for the verification of the MIMO systems through MIMO channel modeling.

Conventional sounder for measuring MIMO channel is based on time division multiplexing(TDM) architecture that sounding signals from each transmit antenna are transmitted utilizing synchronized switch sequentially, not concurrently and uses PN sequence as a sounding signal as represented in Figure 1[2][3]. This TDM-based MIMO channel sounder has a merit of low-cost hardware implementation but is not suitable for channel measurement in fast fading environment because the probing signals from each Tx antenna are transmitted not simultaneously but periodically in proportion to the number of Tx antennas. As a result, a new method to measure the MIMO channel in high mobility accurately has been required.

In this paper, as a solution, code division multiplexing(CDM) based MIMO channel sounding architecture is considered.[4] CDM-based MIMO channel sounder uses an orthogonal code as a probing signal and transmits probing signals from every Tx antenna simultaneously as shown in Figure 1. Therefore this transmit architecture enables the MIMO channel to be measured accurately in high doppler environments. But because there exists no orthogonal code in reality that the property of autocorrelation and cross-correlation is perfect, it is important to find some codes whose correlation properties are the closest with the ideal one.

We propose to use Loosely Synchronous(LS), Kasami and Chaotic sequence which are known for having a very low-correlation property between codes as probing signals for the CDM architecture. After these three sequences are examined and compared through some simulations, the most appropriate sequence as a probing signal is selected. In simulation, 3GPP/WINNER SCME [5] is used as a MIMO channel model and RMS(root mean square) delay spread error and angular spread error for transmission of each sequence are used as a criterion for the performance evaluation.

In sounding environments that lots of transmit antennas are required, the interferences among the signals from each antennas are increased and this makes accuracy of measurements low. As an another contribution, we propose to use a new architecture combining CDM with TDM in these cases. Through another simulation, we can make sure that the proposed architecture outperforms the CDM or TDM one in high doppler environments where 8x8 MIMO are used.

This paper is organized as follows. In section II, three candidate sequences for the probing signal in CDM architecture are introduced. In section III, the performance of measurement among those sequences is compared through simulation and analyzed to select the most appropriate sequence as a probing signal. In section IV, a novel scheme which combines CDM with TDM is explained and simulation results are presented. In the end, the conclusion is discussed in section V.

II. THREE CANDIDATE SEQUENCES FOR PROBING SIGNALS IN CDM ARCHITECTURE

A. Loosely Synchronous Sequence

Composed of ternary, LS sequence can be generated by inserting all zero sequences between Golay complementary pair C and S which have binary values {1,-1} as shown in Figure 2-(A),(B) [6][7]. Its autocorrelation or cross-correlation values are as follows.

$$R_{jk}(\tau) = \sum_{i=1}^{L-1} c_{j,i}c_{k,(i+\tau) \bmod L} = \begin{cases} L, & \tau = 0,\, j = k \\ 0, & \tau = 0,\, j \neq k \\ 0, & 0 < |\tau| < \tau_{IFW} \end{cases} \tag{1}$$

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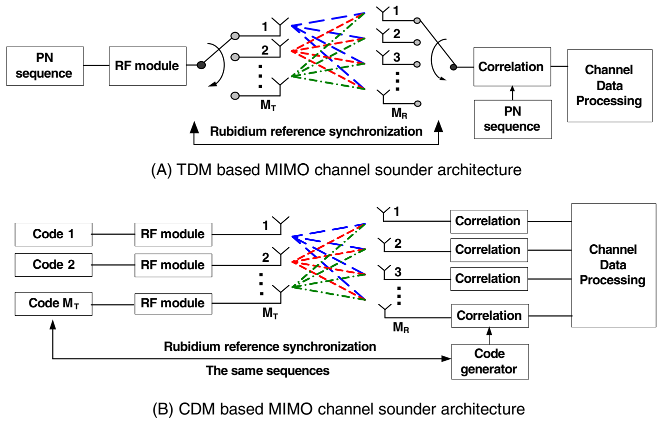

Fig. 1. MIMO channel sounder architecture

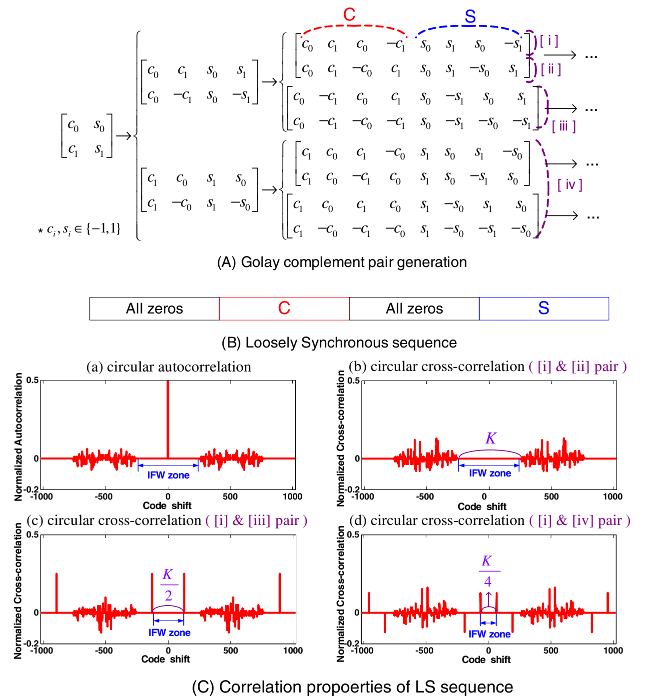

Fig. 2. Loosely Synchronous sequence

where $c_{m,n}$ is n-th element in m-th LS sequence in a set of LS sequences, τ is the delay shift, and L is the length of the sequence. From (1), LS sequence has zero-correlation within specific zone$(0 < |\tau| < \tau_{IFW})$, which is called interference free window(IFW) zone. If any delayed version of a sequence or different sequences are within this zone, we can perfectly distinguish our desired sequence without any interference occurred by autocorrelation or cross-correlation. In other words, the received signals can be analyzed as several single-input single-output (SISO) signals inside IFW zone.

By the way, the width of IFW zone depends on the number of sequences. Figure 2-(C) shows this. If we increase the number of sequences twice, the width of IFW zone is decreased to one half [8]. In this reason, it is estimated that using LS sequence to measure MIMO channel will be inadequate in some situations that many transmit antennas are required or delays of multipaths are longer than the width of IFW zone.

B. Kasami Sequence

Kasami sequence is known for having optimal cross-correlation values touching the Welch lower bound [9]. The autocorrelation and cross-correlation functions of Kasami sequence always take one value among the three values in a set $\{-1, -s(n), s(n)-2\}$ where $s(n) = 2^{n/2}+1$, n is an even number, the length of the sequence is $2^n - 1$, and the number of different Kasami sequences is $2^{n/2}$ [10].

Even though Kasami sequence has optimal low correlation values there are some limitations in case of applying this sequence to MIMO channel sounder. Because the interferences are increased in proportion to the increase of the number of transmitting sequences, dynamic ranges are reduced according as the number of transmit antennas are increased. And the determination of the sequence length is restrictive in that only the length is decided as $2^n - 1$ where n is even number.

C. Chaotic Sequence

Chaotic sequence is a deterministic sequence which is generated sequentially by using a mapping function $x_{n+1} = f(x_n)$ and an initial value x_0 but whose distribution looks like white noise.[11] Mainly used maps are Logistic map, Cubic map, Skew tent map, Henon map, and so on. Among them, one of the simplest and most widely used one is Logistic map which is represented as $x_{k+1} = \mu x_k(1-x_k)$ where $0 \le x_n \le 1$, $0 \le \mu \le 4$, and μ is called the bifurcation parameter [12]. By choosing $3.5699456... \le \mu \le 4$, aperiodic and random sequence is sequentially generated.

Due to the complex nature of non-linear maps, the correlation values of Chaotic sequence cannot be obtained theoretically, but the distribution of the sequence is like white noise because of randomness of sequence generation and this property makes almost uncorrelated between different sequences. Although correlation properties of Chaotic sequence is not optimal, this sequence have a merit that the selection of the sequence length is not restricted.

III. Sequence Selection Based on Simulation Results

A. Simulation Environments

With 3GPP/WINNER spatial channel model extended(SCME), RMS delay spreads and RMS angular spreads are calculated from the received signals when each sequence is transmitted. The number of transmit antennas(sequences) is 2, 4, and 8 and through simulations in both SCME urban macro and SCME suburban macro scenario, we also want to know how maximum excess delay influences on the measurement performance of LS sequence.

For input parameters of SCME, center frequency is 5.3 GHz, the bandwidth of the channel is 100MHz(chip duration is 10ns), mobility is 60 km/h. Receive antennas are 8-element uniform linear array, the chip length of the codes are 4094(LS) and 4095(Kasami, Chaotic), and E_C/N_0 is fixed to 20 dB for focusing on interference among sequences. Delay spread is obtained from power delay profile and angular spread is calculated by using Unitary ESPRIT algorithm [13]. The calculation of RMS delay spread τ_{rms} and RMS angular spread θ_{rms} are as follows.

$$\tau_{rms} = \sqrt{\frac{\int_{-\infty}^{\infty} (\tau - \tau_{mean})^2 P_g(\tau) d\tau}{\int_{-\infty}^{\infty} P_g(\tau) d\tau}}, \tau_{mean} = \frac{\int_{-\infty}^{\infty} \tau P_g(\tau) d\tau}{\int_{-\infty}^{\infty} P_g(\tau) d\tau} \quad (2)$$

$$\theta_{rms} = \sqrt{\frac{\int_{-\pi}^{\pi} (\theta - \theta_{mean})^2 P_g(\theta) d\theta}{\int_{-\pi}^{\pi} P_g(\theta) d\theta}}, \theta_{mean} = \frac{\int_{-\pi}^{\pi} \theta P_g(\theta) d\theta}{\int_{-\pi}^{\pi} P_g(\theta) d\theta} \quad (3)$$

RMS delay spread error and angular spread error is calculated from the absolute difference of RMS delay spread and angular spread between measured channel and SCME, and represented as the form of CDF. From the CDF graph we can compare RMS delay and angular spread error performance among the sequences.

B. Simulation Analysis and Sequence Selection

The effects on channel measurements according to the increase of the number of transmit antennas from 2 to 8 are examined respectively in urban macro and suburban macro environment.

Figure 3 represents the simulation results with regard to RMS delay spread error. From the results, we can know that irrespective of the number of transmit antennas and scenarios, the performance of LS sequence is better than two others because of perfect zero-correlation within IFW zone. But in the case of 8 transmit antennas in urban macro, the errors are increased abruptly. We can explain that because IFW zone is narrowed in proportion to the number of sequences, the number of multipaths with longer delays than IFW width are relatively increased and these multipaths cause large delay spread errors. This analysis can also explain in the same way why in suburban macro scenario which represents relatively short delays the performance of LS sequence is not degraded.

Figure 4 is the results of the experiment about RMS angular spread errors. Like the case of delay spread errors, LS sequence outperforms the other sequences. However, large degradation is not showed according to the increase of the transmit antenna in both scenario unlike Figure 3. This is because angular spread is influenced less on some long-delayed multipaths having relatively low power.

As a result, we can conclude that LS sequence as a probing signal for the channel sounder is the most appropriate.

IV. Hybrid Architecture of CDM and TDM

Through the simulations it is hard to use LS sequence in CDM-based channel sounder when the number of antennas are more than 4. To support more antennas we propose a hybrid scheme to combine CDM with TDM and Figure 5 shows the architecture. In this architecture, after total transmit antennas M_T into K groups, signals from the K number of transmit antennas in the first group are transmitted concurrently with

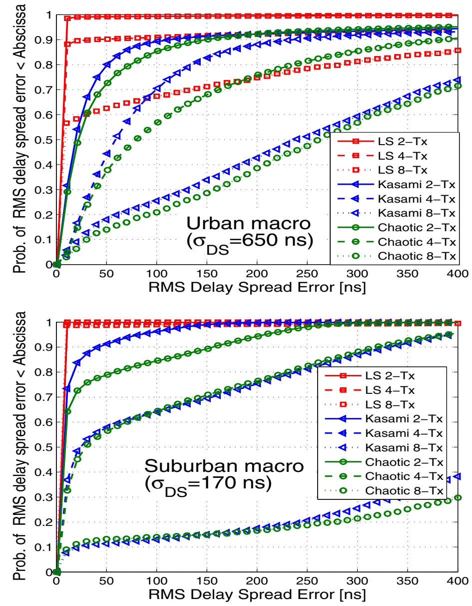

Fig. 3. CDF of RMS delay spread error in Urban & Suburban macro

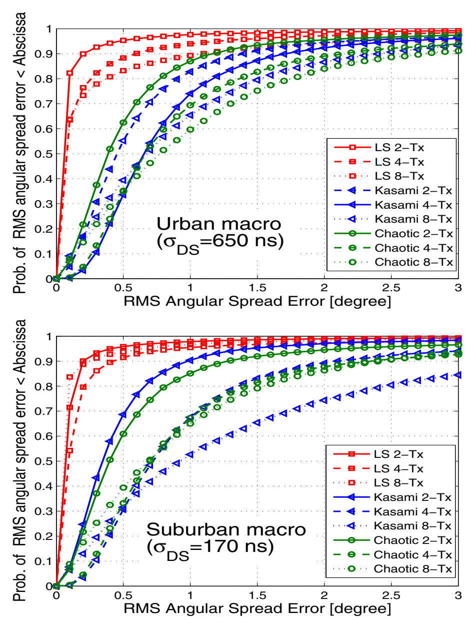

Fig. 4. CDF of RMS angular spread error in Urban & Suburban macro

CDM technique. Then another group of K number of transmit antennas is transmitted and this process is finished after the last group is transmitted. In the end transmission of the groups is TDM technique. Because this scheme uses both code and time to multiplex multiple transmit antennas, by adjusting the proportion of code and time carefully, the performance of measurement can be improved.

The performance of the proposed scheme is obtained through the same process with the previous simulation and compared with TDM and CDM. In this simulation, only 8x8 MIMO and urban macro scenario are used because LS

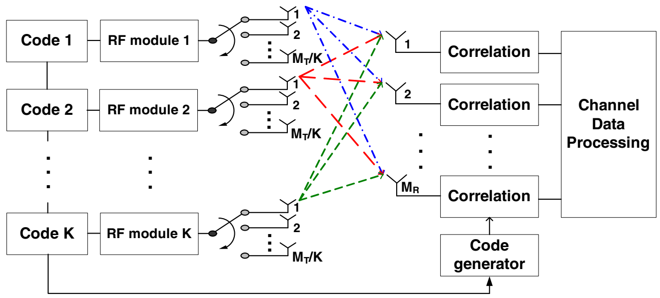

Fig. 5. Hybrid architecture of CDM and TDM

sequence represented bad performance in this environment and the mobility of SCME is set to 0, 60, 120, and 350 km/h to examine performance of the schemes according to the channel variations. Other parameter settings and criteria of performance are the same with the previous simulation.

Figure 6 and Figure 7 represent the simulation results with regard to RMS delay spread error and RMS angular spread error. When the mobility is stationary(0 km/h), TDM is the best due to the no concurrent transmission as we expected. But as the channel variations are increased, the performance of TDM is degraded the most abruptly due to the long measurement-time for a channel snapshot. On the contrary the accuracy of CDM scheme is hardly irrespective of channel variability. Totally in every channel variation environment, we can find that Hybrid scheme with $K = 2, 4$ represents good performance by and large. Therefore the proposed scheme can be utilized when the performance of CDM architecture is not good.

V. Conclusions

By using CDM based MIMO channel sounder, we can measure MIMO channel with fast variation accurately. In this paper we examined some candidate sequences applicable for CDM architecture and compared the performance of channel measurement among the sequences. As a result, LS sequence can be more preferred than Kasami and Chaotic sequence in case of 2, 4, and 8 transmit antennas. And by proposing hybrid architecture of CDM and TDM when the number of transmit antennas is more than 4, we validated through simulations that accuracy of the measurement can be enhanced.

References

[1] J. Kivinen, T. O. Korhonen, P. AiKio, R. Gruber, P. Vainikainen, S.G. Haggman, "Wideband radio channel measurement system at 2GHz," *IEEE Trans. Instrum. Meas.*, vol. 48, issue 1, pp.39-44, Feb. 1999.

[2] MEDAV RUSK MIMO Channel Sounder Manual.

[3] Elektrobit PROPsound MIMO Channel Sounder Manual.

[4] K. SAKAGUCHI, J. TAKADA, K. ARAKI, "A Novel Architecture for MIMO Spatio-Temporal Channel Sounder," *IEICE Trans. Electron*, vol.E85-C, no.3, pp.436-431, Mar. 2002.

[5] D. S. Baum, J. Salo, G. Del Galdo, M. Milojevic, P. Kyosti, and J. Hansen, "An interim channel model for beyond-3G systems," in *IEEE Vehicular Technology Conference*, 2005, VTC 2005-Spring, pp. 3132-3136.

[6] S. Stanczak, H. Boche, M. Haardt, "Are LAS-codes a miracle?," in *IEEE Global Communications Conference*, 2001, vol. 1, pp. 589-593.

[7] Pingzhi Fan, "Spreading sequence design and theoretical limits for quasisynchronous CDMA systems," EURASIP J. *Wireless Commun. and Networking*, vol.1, pp.19-31, 2004.

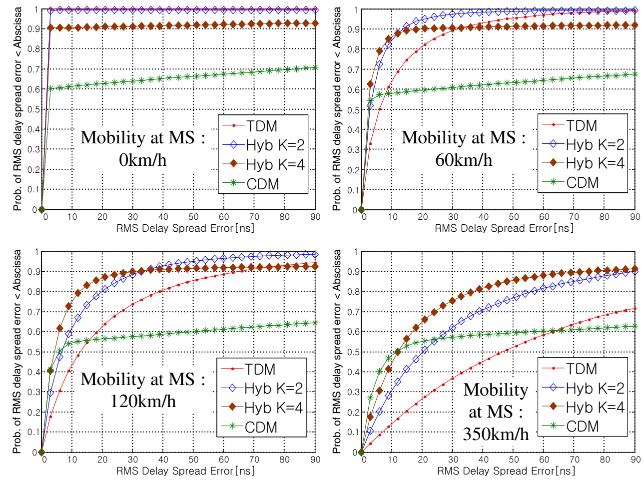

Fig. 6. RMS delay spread errors with various channel variations

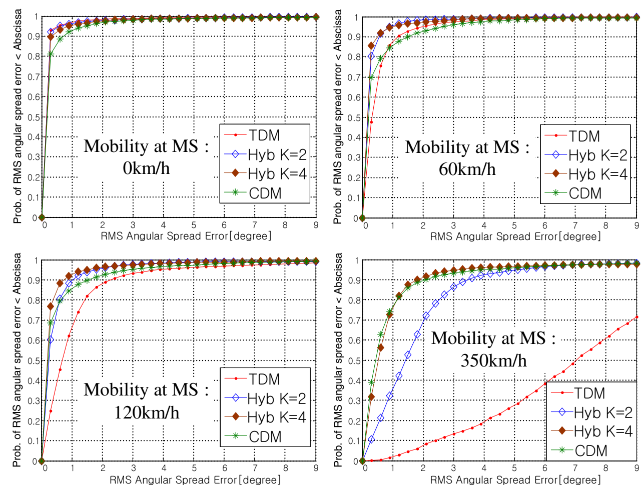

Fig. 7. RMS angular spread errors with various channel variations

[8] Ji Hwan Choi, Hyun Kyu Chung, Hyunseok Lee, Jongsub Cham and Hyuckjae Lee, "Code-Division Multiplexing based MIMO channel sounder with Loosely Synchronous Codes and Kasami Codes", in *IEEE Vehicular Transportation Conference*, 2006, VTC 2006-fall, pp.1-5.

[9] J. G. Proakis, *Digital Communications*, Mc-Graw Hill International Editions, 3rd edition, 1995.

[10] A. M. D. Turkmani, U. S. Goni, Performance evaluation of maximal-length, gold and Kasami codes as spreading sequences in CDMA systems, in *IEEE International Conference on Universal Personal Communications*, 1993, vol.2, pp.970-974.

[11] G. Heidari-Bateni and C. D. McGillem, Chaotic sequences for spread spectrum: An alternative to PN-sequences, in *IEEE International Conference on Selected Topics in Wireless Communications*, 1992, pp. 437-440.

[12] Devaney R.L., , *An Introduction to Chaotic Dynamical Systems*, Addison-Wesley Publishing Company, Inc., California, 1989.

[13] Martin Haardt and Josef A. Nossek, "Unitary ESPRIT: How to Obtain Increased Estimation Accuracy with a Reduced Computational Burden," *IEEE Trans. Signal Process.*, vol. 43, no. 5, pp.1232-1242, May 1995.