Time-Division Multiplexing based MIMO Channel Sounder using Loosely Synchronous Codes

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Abstract—In this paper, we propose the time-division multiplexing (TDM) based MIMO channel sounding technique using loosely synchronous (LS) codes for real time measurement of MIMO radio channel. Since LS codes have perfect auto-correlation and cross-correlation functions within certain vicinity of the zero shifts, the proposed technique can substantially reduce multipath channel interference. When cumulative distribution functions (CDFs) of absolute Root Mean Square (RMS) delay spread error are considered, simulation results show that the proposed technique outperforms the conventional TDM based MIMO channel sounding technique. Moreover, in the MIMO channel environment where a mobile station moves with various speeds, the proposed technique is more efficient than the conventional TDM based MIMO channel sounding technique, because the proposed technique obtains about twice the measurement data of the conventional TDM based MIMO channel sounding technique at given time slots.

Keywords- CDF, LS codes, RMS delay spread error, TDM based MIMO channel sounding technique.

I. INTRODUCTION

Multiple-input multiple-output (MIMO) antenna systems have recently gained considerable interest as they offer high data throughput and significant enhancement in link reliability over single antenna systems without requiring additional power or bandwidth. Since performance of the MIMO system depends on the behavior of the MIMO channel, efficient system for mobile communication requires accurate knowledge of channel characteristics. The MIMO channel is considered to be parameterized by time-delay, complex path weight, direction of arrival (DOA), direction of departure (DOD), which can be obtained by analyzing measurement data. So, the measurement data of MIMO channel are important issues in many aspects like performance analysis and system design. Channel sounders should therefore provide the temporal and spatial characteristics of the MIMO channel with accuracy and resolution high enough to benefit the design purpose. In TDM based MIMO channel sounding technique [8], the number of antennas at both transmitter and receiver limits its capability, with a trade-off between spatial resolution and time resolution. However, for the sake of reduced cost and complexity, most of the commercial MIMO channel sounders use single, time-multiplexed, transceiver architecture [1-2]. Another approach is code-division multiplexing (CDM) based MIMO channel sounding technique, which has the merit of real time measurement. However, it has the disadvantage that dynamic range of the system is limited by transmitter antenna arrays due to the cross-correlation between different codes.

In this paper, we propose the TDM based MIMO channel sounding technique using LS codes. LS codes [4], one of the smart codes based on Golay complementary pairs (GCP) [3], have the zero correlation zone (ZCZ) or Interference Free Window (IFW). It is proposed that the multiple antennas and multipath interference can be significantly reduced by utilizing the ZCZ or IFW. Since LS codes have perfect auto-correlation and cross-correlation functions within certain vicinity of the zero shifts, proposed technique can substantially reduce multipath channel interference. We focus on finding CDF of absolute rms delay spread error of the proposed technique in terms of the 3GPP Spatial Channel Model Extended (SCME) [5-6].

The outline of this paper is as follows. In section II, The conventional TDM based MIMO channel sounding technique is described. In section III, properties of LS codes are described. In section IV, the proposed MIMO channel sounding technique is described. Finally section V and VI give simulation results and conclusions respectively.

II. THE TDM BASED MIMO CHANNEL SOUNDING TECHNIQUE

A. The conventional TDM based MIMO channel sounding system

The conventional TDM based MIMO channel sounding system [8] is depicted in Fig.1. The system uses \( N \) transmitter (Tx) and \( M \) receiver (Rx) antennas. Generated Pseudo-Noise (PN) code sequences for each transmission antenna propagates to MIMO channel. At the receiver, Channel Impulse Response (CIR) is observed after sliding correlation of Pseudo-Noise (PN) code sequences with the received signal.
III. LOOSELY SYNCHRONOUS CODES

A. Properties of uncorrelated LS codes in interference free window

LS codes are defined as the combination of C and S subsequences, a Golay complementary pair, with zeros inserted to avoid overlapping between the two subsequences. If \((C_0, S_0)\) and \((C_1, S_1)\) are both Golay pairs of LS codes, we say that two LS codes are a mate. Fig. 2 shows a simple example of LS codes whose components are equal to ±1 or 0. As a result of inserted zeros, LS codes have features that aperiodic auto-correlation sidelobes and cross-correlations are zero within IFW \(W_0\). Fig. 3 shows auto-correlation and cross-correlation properties of a mate with length \(L = 64\) and IFW \(W_0 = 32\).

B. Properties of correlated LS codes in interference free windows

The main purpose of zeros insertion of the LS codes is to avoid the sequences \(C_0\) and \(C_1\) overlapping with the sequences \(S_0\) and \(S_1\). Note that it is also necessary to insert enough guard intervals between sequences with length longer than the maximum delay of the multipath channel. Under the assumption that \(W_0/2\) is the maximum delay of the multipath channel without decreasing the energy efficiency suggested in [4], we define that the length of IFW \(W_0\) is equal to \(L_p - 1\), where \(L_p\) is length of a complementary pair. As shown in Fig.4, if use Golay codes of \(L_p = 16\) which are generated by using Hadamard matrix [4], the properties of possible IFWs are as follows;

III.B.1) Set 1, 2, 3 and 4 are mates, respectively.
III.B.2) If set 1 is initial mate, IFW between set 1 and 2 is \(W_0/2\).
III.B.3) If set 1 is initial mate, IFW between set 1 and 3 is \(W_0/4\).
III.B.4) If set 1 is initial mate, IFW between set 1 and 4 is \(W_0/4\).
III.B.5) If set 2, 3 or 4 are initial mates respectively, properties of IFWs among three other mates are the same as the set 1, the initial mate.

For the mates having length \(L = 128\) and IFW \(W_0 = 64\), Fig. 5 shows four weakly correlated cross-correlations

\[
\begin{bmatrix}
C \\
S
\end{bmatrix}
\]
\[
\downarrow zeros
\]
\[
\begin{bmatrix}
C \\
zeros \\
C \\
zeros \\
S
\end{bmatrix}
\]

Figure 2. Formation of LS codes
IV. THE PROPOSED TDM BASED MIMO CHANNEL SOUNDING TECHNIQUE

A. The proposed TDM based MIMO channel sounding system

As shown in Fig. 6, we propose the TDM based MIMO channel sounding technique using LS codes for real time measurement of MIMO radio channel. We assume that the system uses $N$ Tx and $M$ Rx antennas. At the transmitter, two transmission antennas simultaneously transmit a mate of LS codes at a given time slot. After transmitting a mate from the first two antennas, another two transmission antennas also transmit a mate and so on. At the receiver, we can get the MIMO channel by taking respective cross correlation between received signals and LS codes. If we assume that the maximum delay dispersion of the MIMO radio channel is less than IFW $W/2$, the received signals of $2 \times M$ system at the first time slot can be represented respectively as

$$
\begin{align*}
y_1(t) &= h_{11}(t) * c_1(t) + h_{12}(t) * c_1(t) + w_1(t), \\
y_2(t) &= h_{21}(t) * c_1(t) + h_{22}(t) * c_1(t) + w_1(t), \\
\vdots \\
y_{M-1}(t) &= h_{M-1,1}(t) * c_1(t) + h_{M-1,2}(t) * c_1(t) + w_{M-1}(t), \\
y_M(t) &= h_{M,1}(t) * c_1(t) + h_{M,2}(t) * c_1(t) + w_M(t),
\end{align*}
$$

(1)

where “$*$” denotes the convolution, $(c_i(t), c_j(t))$ is a mate of LS codes at time $t$, each has length $L$, both $h_i^j(t,t)$ and $h_{i,j}^j(t,t)$ are time domain response of channel for $i=1,\cdots,M$, $w_i$ is AWGN for $j=1,\cdots, M$. At the receiver, we can get the channel by taking respective cross correlation between received signals and LS codes. The MIMO channel can be written as follows:

$$
\begin{align*}
\hat{h}_1 &= R_{w,M}(m) = h_1 + R_{w,M}(m) + h_{21}(m), \\
\hat{h}_2 &= R_{w,M}(m) = h_2 + R_{w,M}(m) + h_{22}(m), \\
\hat{h}_3 &= R_{w,M}(m) = h_3 + R_{w,M}(m) + h_{31}(m), \\
\hat{h}_4 &= R_{w,M}(m) = h_4 + R_{w,M}(m) + h_{42}(m), \\
\hat{h}_5 &= R_{w,M}(m) = h_5 + R_{w,M}(m) + h_{53}(m), \\
\hat{h}_6 &= R_{w,M}(m) = h_6 + R_{w,M}(m) + h_{64}(m), \\
\hat{h}_7 &= R_{w,M}(m) = h_7 + R_{w,M}(m) + h_{75}(m), \\
\hat{h}_8 &= R_{w,M}(m) = h_8 + R_{w,M}(m) + h_{86}(m),
\end{align*}
$$

(2)

where $R_{a,b}(m)$ is the aperiodic auto-correlation of $a$ and $b$, $R_{a,b}(m)$ is the aperiodic cross-correlation of $a$ and $b$. Because the maximum delay dispersion of the MIMO channel is less than IFW $W/2$, the proposed technique can substantially reduce multipath channel interference by taking respective cross-correlation.

B. RMS Delay Spread

In practice, a set of channel parameters are in use to characterize the multipath behavior of a MIMO radio propagation channel. These parameters can be obtained from measurement data of MIMO channel. Because of multipath
propagation, a received signal will suffer spreading in time compared to the transmitted signal and this effect is called delay spread. Delay related parameters can be extracted from a measured power delay profile (PDP). One of the most widely used parameters is RMS delay spread. RMS delay spread is the square root of the second central moment of the PDP. To derive the RMS delay spread from measured PDPs, all relevant paths should be taken without knowledge of noise peak. The calculation of RMS delay spread is as follow;

$$\tau_{\text{rms}} = \sqrt{\int_{-\infty}^{\infty} (\tau - \tau_{\text{rms}})^2 P_g(\tau)d\tau}$$

(3)

where $\tau_{\text{rms}}$ is mean excess delay. The computation of $\tau_{\text{mean}}$ is as follow;

$$\tau_{\text{mean}} = \frac{\int_{-\infty}^{\infty} \tau P_g(\tau)d\tau}{\int_{-\infty}^{\infty} P_g(\tau)d\tau}$$

(4)

Note that RMS delay spread has to be calculated concerning a reasonable threshold for the multipath noise floor. In this paper, the threshold of the PDPs for RMS delay spread is set to -40dB.

V. SIMULATION RESULTS

We choose that a PN code sequence is fixed with 1023, a LS code length is fixed with 1024, IFW $W_0$ of a LS code is 512, $E_c/N_0$ is 40dB, the channel bandwidth is 100 MHz (chip resolution is 10 ns), center frequency is 5.3 GHz, mobile speeds are 0 km/h, 120 km/h and 300 km/h. We also choose 2×8 system and 4×8 system respectively. We assume that the maximum delay dispersion of the MIMO channel is less than IFW $W_0/2$.

The simulated channel is generated by using 3GPP SCME released by Wireless World Initiative New Radio (WINNER) project. This channel generates 6 paths composed with 4 intra clusters individually. The simulation results are analyzed separately corresponding to two scenarios which are urban micro and suburban macro. We focus on CDF of absolute RMS delay spread error to analyze the performance when CDF has the value 95%.

Firstly we consider urban micro environment. In Fig. 7 (a), (b) and (c), the proposed technique using LS codes has better performances than those of the conventional TDM based sounding technique with any $E_c/N_0$, because of the IFW zone of LS codes. In Fig. 7 (c), the proposed 2×8 and 4×8 MIMO channel sounder have a little better performance by about 2ns and 4ns as compared with the conventional 2×8 and 4×8 TDM based sounder at the CDF of 95% respectively. Secondly, we consider suburban macro environment. As shown in Fig. 8 (a), (b) and (c), the performance results of the proposed sounder and conventional TDM based sounder in suburban macro channel are almost the same for those in urban micro channel. Moreover, in the MIMO channel environment where a mobile station moves with various speeds, the proposed technique is more efficient than the conventional TDM based MIMO channel sounding technique, because the proposed technique obtains about twice the measurement data of the conventional technique at given time slots.

Figure 7. Absolute error of RMS delay spread in urban micro MIMO channel
VI. CONCLUSIONS

In this paper, the TDM based MIMO channel sounding technique using LS codes is proposed. The effect of proposed technique on RMS delay spread is analyzed in terms of the 3GPP SCME. When we consider the performance of RMS delay spread error, the simulation results show that the proposed technique has better performances than those of the conventional TDM based MIMO channel sounding technique in the MIMO channel environment where the maximum delay dispersion of the MIMO channel is less than IFW $W_0/2$. Moreover, in the MIMO channel environment where a mobile station moves with various speeds, the proposed technique is more efficient than the conventional TDM based MIMO channel sounding technique because the proposed technique obtains about twice the measurement data of the conventional TDM based MIMO channel sounding technique at given time slots.

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