A New Approach to Estimating the MIMO Channel in Wireless Networks

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Abstract—This paper investigates on the use of constant-amplitude zero-autocorrelation (CAZAC) sequence for channel estimation in multiple-input multiple-output (MIMO) system over indoor wireless channel. Since the symbol-length of the conventional 4-phase CAZAC sequence is short, there is a limitation to use it for MIMO system in multipath environments. An algorithm which generates longer CAZAC sequences is proposed to overcome that problem. Flexible symbol-length of 4-phase CAZAC sequences can be made by the proposed algorithm. Therefore appropriate symbol-length of CAZAC sequences could be utilized as preambles in accordance with the number of transmit antennas and channel condition. The effect of the number of CAZAC sequences for channel estimation is presented in terms of mean square error (MSE).

Index Terms—MIMO, channel estimation, CAZAC, MSE.

I. INTRODUCTION

IN wireless communication system, one of the most dominant factors causing the performance degradation is channel estimation error. It has been studied for a long time to acquire accurate channel state information. A channel estimation technique using the constant-amplitude zero-autocorrelation (CAZAC) sequence which holds outstanding periodic autocorrelation property is one of the well-known algorithms [1]. It has been used as a training sequence in the IEEE 802.15.3 standards.

For the multiple-input multiple-output (MIMO) system that uses multiple antennas to get better reliability and higher transmission rate, channel estimation is more important than single antenna system to distinguish combined signals. Although 4-phase, 16-symbol-length CAZAC sequence can be adopted in MIMO system with simple technique [2], its capability of channel estimation is limited by the number of transmit antennas and multipath components to maintain the orthogonality. In this paper, we provide an algorithm which generates extended CAZAC (E-CAZAC) sequences to overcome that limitation. We show the simulation results of the performance of CAZAC sequence according to the number of multipath components and transmit antennas over Rayleigh fading channel in terms of mean square error (MSE). The impact of the number of CAZAC sequences for channel estimation is also presented.

The rest of the paper is organized as follows. In Section II, we gives system and channel models. Thereafter, the proposed algorithm for multiple-antenna system is presented in Section III. In Section IV, the performance of the proposed scheme is evaluated in terms of MSE with some discussions. Finally we make conclusions in Section V.

II. SYSTEM AND CHANNEL MODELS

A. System model

We introduce IEEE 802.15.3 high rate wireless personal area network (HR-WPAN) system with multiple antennas as a system model. IEEE 802.15.3 standards specify that the preamble contains 12 periods of 4-phase, 16-symbol-length CAZAC sequences. The last CAZAC sequence is a 180 degrees rotated version of original one to notice the end of the CAZAC preamble.

CAZAC sequence has the features of constant-amplitude and zero-autocorrelation which provide good and rapid signal acquisition performances even for low SNR conditions. The properties of CAZAC sequence is preserved both in time and frequency domain. Therefore, it is used for not only channel estimation but also synchronization.

B. Channel model

A short range indoor channel can be described by a Rayleigh fading model with an exponentially decaying profile [3], [4]. The maximum number of resolvable paths P_{MAX} is calculated by following equation:

$$P_{\text{MAX}} = 10\frac{T_{\text{RMS}}}{T_s} \quad (1)$$

where T_{RMS} denotes root mean square (RMS) delay spread and T_S stands for a reciprocal of signal bandwidth. Practically, short range indoor

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TX 1	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
TX 2	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_0	C_1	C_2	C_3
TX 3	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
TX 4	C_{12}	C_{13}	C_{14}	C_{15}	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}

Fig. 1 The structure of each 16-length CAZAC sequence as a preamble for 4-transmit-antenna system.

channels usually produce a delay spread of 25-75 ns at 2.5 GHz in frequency [5]. In other words, HR-WPAN system suffers from 8 paths at most. If we introduce N_t transmit antennas and N_r receive antennas to the system, there are $N_t \cdot N_r$ channel branches between the transmitter and the receiver. We assume each of the channels is mutually independent. Besides, it is also supposed that channel variation is fixed for one frame. The baseband channel impulse response (CIR) of s-th channel branch $h_s(t)$ can be written as

$$h_s(t) = \sum_{p=1}^{P} \alpha_p \delta(t - pT_s) \quad for\ s = 1, 2, \cdots, N_t N_r \tag{2}$$

where α_p means magnitude of p-th CIR and δ represents the unit impulse function.

III. EXTENSTION OF CAZAC SEQUENCE

The conventional 4-phase, 16-symbol-length CAZAC sequence **c** can be determined by

$$c_{4m+n} = j^{mn} \tag{3}$$

where $j = \sqrt{-1}$, $m = n \in \{0, 1, 2, 3\}$. Therefore,

$$\mathbf{c} = \{ 1, 1, 1, 1, 1, j, -1, -j, 1, -1, 1, -1, 1, -j, -1, j \}. \tag{4}$$

It is noted that when each element of c is phase-rotated by 45-degree and is multiplied by square root of 2, it turns into the training sequence in the IEEE 802.15.3 standards. 16-symbol-period is adequate to manage an overall symbol response including delay spread channel for indoor HR-WPAN system with single antenna. However, if multiple antennas are employed, the orthogonality of CAZAC sequence cannot be guaranteed any more. The reason would be found from Figure 1 which illustrates the structures of each 16-symbol-length CAZAC sequence for 4-transmit-antenna system. Since the minimum phase difference among those CAZAC sequences is 4, the orthogonality of CAZAC sequence must be destroyed in case more than 4 paths exist. From [2], we deduce generalized relation to determine the number of distinguishable paths D as follows:

$$1 \le D \le \frac{L}{T} \tag{5}$$

where L indicates the symbol-length of CAZAC sequence.

It is obvious that conventional 4-phase, 16-symbol-length CAZAC sequence is not suitable for a preamble for HR-WPAN system with more than 2-transmit-antenna to estimate the channel state information. So, we suggest an algorithm to make longer CAZAC sequence while 4-phase is preserved. The algorithm for E-CAZAC sequence is shown in following equation:

$$e_{mL/4+n} = \begin{cases} j^{mn} & for\ n < 4 \\ 0 & otherwise \end{cases} \tag{6}$$

where $m \in \{0, 1, 2, 3\}$, $n \in \{0, 1, \cdots, L/4-1\}$. It is remarked that L must be the multiples of 4. Since several zeros are padded, the peak autocorrelation value is constrained to 16 even if symbol-length is extended. On the other hand, noises are negligible for zero-padded parts. Moreover, the complexity of calculation is fixed because only 16 components are required for correlation. If L is equal to 32, then

$$\begin{aligned} \mathbf{e} = \{ & 1, 1, 1, 1, 0, 0, 0, 0, 1, j, -1, -j, 0, 0, 0, 0, \\ & 1, -1, 1, -1, 0, 0, 0, 0, 1, -j, -1, j, 0, 0, 0, 0 \}. \end{aligned} \tag{7}$$

Since such zero paddings do not provide any additional information about the power spectrum [6], flat power spectrum of CAZAC sequence is inherited. It means ECAZAC sequence keeps zero-autocorrelation property. T-he proof of zero-autocorrelation property of CAZAC sequence using discrete Fourier transform (DFT) can be found in [1]. Strictly speaking, E-CAZAC sequence does not present constant-amplitude. However, it can be viewed that upsamplings are done at zero-padded parts. Consequently, E-CAZAC sequence follows the benefit of strict sense CAZAC sequence.

One may think other CAZAC sequences with higher phase are better solution for MIMO system because all symbols are used for estimation. However, it has higher phase to make longer sequence which causes higher complexity of transmitter. Besides, it uses more power for transmission and correlation. Our technique, E-CAZAC, enables conventional 4-phase CAZAC sequence to be used for MIMO system with low hardware complexity and low power-consumption.

IV. PERFORMANCE EVALUATION AND DISCUSSIONS

In this section, we evaluate the performance of proposed E-CAZAC sequence in terms of MSE. The MSE is one of the most common measures to appraise

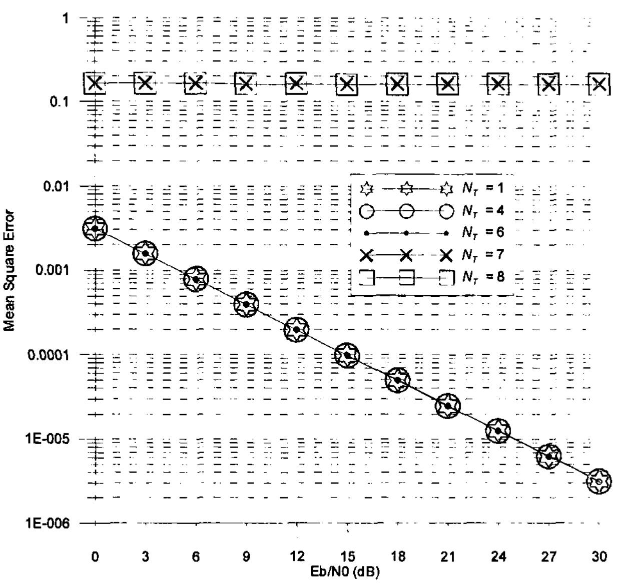

Fig. 2 The MSE performances of 32-symbol-length E-CAZAC sequence for 1, 4, 6, 7, and 8 transmit antennas over 5-path Rayleigh fading channel.

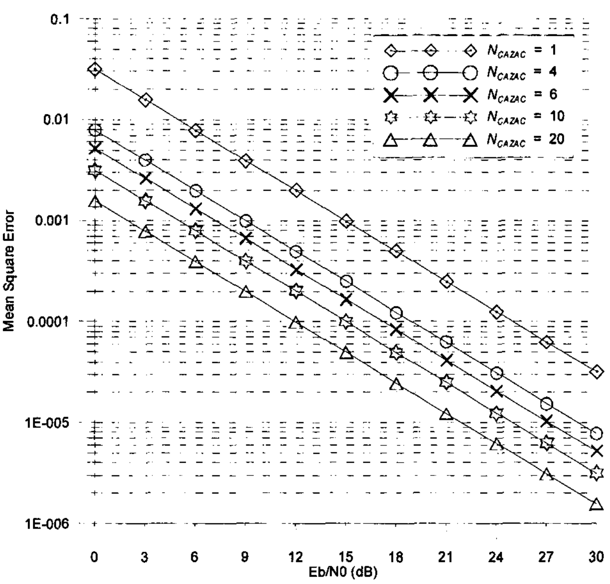

Fig. 3 The effect of the number of CAZAC sequences for estimating the channel state information on MSE performance.

the quality of estimator which shows the error variance. It can be calculated as below:

$$\mathrm{MSE} = \mathrm{E}\left[(\mathbf{h}-\hat{\mathbf{h}})(\mathbf{h}-\hat{\mathbf{h}})^H\right] \quad (8)$$

where $\mathbf{h} = [\ h(T_s)\ h(2T_s) \cdots h(pT_s)\ ]$, $\hat{\mathbf{h}}$ denotes the estimated value of $\mathbf{h}$, and $(\cdot)^H$ represents complex conjugate (Hermitian) transpose of $(\cdot)$. Here, we adopt the least square (LS) estimator for simulation.

Figure 2 displays the MSE performances of 32-symbol-length E-CAZAC sequence when 5 paths are presence. In the simulation, 10 CAZAC sequences which are the phase rotated forms of e in equation (7) are utilized for estimating the channel state information. It can be seen that E-CAZAC sequence performs completely when up to 6 transmit antennas are used. In the other cases, MSE performances are very poor because the orthogonality of E-CAZAC sequence is broken. We notice that such situation is out of capability for CAZAC sequence from the equation (5). If 40-symbol-length E-CAZAC sequences are used for 7 and 8 transmit-antenna system, they will estimate the channel nicely.

The effect of the number of CAZAC sequences for channel estimation is shown in Figure 3. We confirm that the more CAZAC sequences are used for estimation, the better MSE performance is acquired. Though E-CAZAC generator provides flexible symbol-length of CAZAC sequences, unnecessarily long length of preamble is impractical as well as useless. In practice, the symbol-length and the number of CAZAC sequences need to be properly restricted in conformity with the system and channel conditions.

IV. CONCLUSIONS

In this paper, we have suggested the extended version of CAZAC sequence to overcome the limitation of conventional one about estimating the channel for MIMO system in multipath environments. The proposed E-CAZAC sequence generator allows appropriate symbol-length of 4-phase CAZAC sequences could be used in conformity to the number of transmit antennas and channel environments. The simulation result have shown that proposed scheme fulfills perfectly for multiple-antenna system if sufficient symbol-length of CAZAC sequences are employed.

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REFERENCES

[1] A. Milewski, "Periodic sequences with optimal properties for channel estimation and fast start-up equalization," *IBM J. Res. Develop.*, vol. 27, pp. 425-528, Sep. 1983.

[2] Dong-Jun Cho, Young-Hwan You, and Hyoung-Kyu Song, "Channel Estimation with Transmitter Diversity for High Rate WPAN Systems," *IEICE Trans. Commun.*, vol. E87-B, no.11 Nov. 2004.

[3] IEEE 802.11a 802.11-98/156-r2, "Updated submission template for Tga-revision2."

[4] IEEE P802.15-00/110r13, "IEEE 802.15.3 (TG3) criteria definitions," Sep. 2000.

[5] IEEE Std P802.15.3-2003, 2003.
[6] J. G. Proakis and D. G. Manolakis, *Digital Signal Processing*, Prentice Hall, New Jersey.

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