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A Study on MIMO-OFDM Modems for Adaptive Frequency Domain Channel Estimator

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Abstract*- This paper presents an adaptive frequency-domain channel estimator (FD-CE) for equalization of space–time block code multiple-input multiple-output (MIMO) orthogonal frequency-division multiplexing (OFDM) systems in time-varying frequency-selective fading. The proposed adaptive FD–CE ensures the channel estimation accuracy in each set of four MIMO-OFDM symbols. Performance evaluation shows that the proposed method achieved a 10% packet error rate of 64 quadrature amplitude modulation (QAM) at 29.5 dB SNR under 120 km/h (Doppler shift is 266 Hz) in 4x4 MIMO-OFDM systems. To decrease complexity, the rich feature of Alamouti-like matrix is exploited to derive an efficient very large-scale integration (VLSI) solution. Finally, this adaptive FD-CE using an in-house 0.13- m CMOS library occupies an area 3x3.1 mm2, and the 4x4 MIMO-OFDM modem consumes about 62.8 mW at 1.2 V supply voltage.

***Indexed Terms*- Adaptive equalizers, multiple-input multiple-output (MIMO) systems, orthogonal frequency-division multiplexing (OFDM), VLSI.**

I. INTRODUCTION

Many studies have investigated MIMO detection, and developed and implemented equalization algorithms [3]–[8]. A scalable STBC decoder [3], supporting 2 x 2, 8 x 3, and 8 x 4 STBCs, was implemented using a low-computational symmetric approach. A 2 x 2 MIMO-OFDM detector [4] was developed to offer two modes of space–frequency block code and space-division multiplexed OFDM. A vertical-bell laboratory-layered space–time (V-BLAST) detector [5] was based on the square-root algorithm for 4 4 MIMO-OFDM systems. These systems are developed for low mobility. For time-varying environments, Akhtman and Hanzo [6] proposed a decision-directed channel estimation scheme utilizing pilot tnes. Song and Lim [7] presented a channel estimation based on particular pilot formats.

The channel correlation function [8] was also proposed to exploit the time-varying effects. However, most methods require high complexity and specific pilot formats. To increase throughput, the number of pilots in MIMOOFDM systems must be significantly smaller than that of data carriers. The objective of this study is to derive an adaptive frequency-domain channel estimator (FD-CE) for frequency-domain equalization without scattered pilots and specific pilot formats in MIMO-OFDM wireless local area network (WLAN) applications over time-varying fading. Conversely, a nonpilot-based channel estimator is built to provide acceptable performance. In the proposed FD-CE, all data carriers are applied to measure channel variations, namely, virtual pilots. Consequently, the system with 64 quadrature amplitude modulation (QAM) can achieve a 10% packet error rate at 29.5 dB SNR at 120 km/h (Doppler shift is 266 Hz). Furthermore, the adaptive FD-CE utilizes the rich property of an Alamouti- like matrix to derive an efficient architecture for VLSI implementation. By using an in-house 0.13m CMOS library, the chip area of the 4 x 4 MIMO-OFDM modem is 4.6 x 4.6 mm and power consumption is 62.8 mW at 1.2V supply voltage.

A. Modem Specification

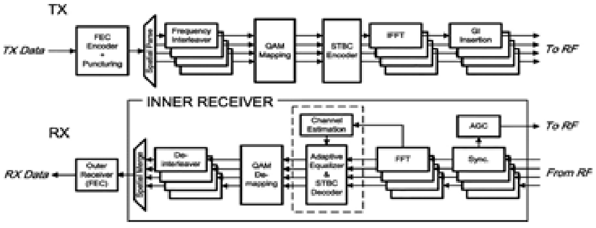

Fig. 1. 4 x 4 MIMO-OFDM modem

Fig. 1 presents a block diagram of the 4 x 4 MIMO-OFDM modem. First, source data is scrambled and then encoded by the convolutional encoder. The encoded bit stream is punctured to the required data rate. According to the number of transmit antennas, the punctured bit stream is parsed into spatial streams. To prevent a burst error, the interleaver changes the bit order for each spatial stream. The interleaved sequence is modulated by the binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), 16-QAM, or 64-QAM scheme. The STBC encoder is then applied to encode the modulated OFDM (with 64-point IFFT) symbols. Each OFDM symbol has 64 subcarriers, 52 of which are data carriers and 12 are pilots and null carriers. The time-domain signal is preceded by the guard interval containing the last 16 samples of the OFDM symbol. After all this, the signal is then transmitted by the RF modules. The receiver synchronizes the received signals to recognize the OFDM symbols. After fast Fourier transform (FFT), the OFDM symbols are decoded by the STBC decoder with the proposed method. Spatial streams are demodulated to bit-level streams, which are then de-interleaved and merged into a single data stream. Finally, the data stream is decoded by the forward error correction (FEC) block, which has a depuncturer, Viterbi decoder, and descrambler.

B. Problem Statement

In time-varying fading, the system must measure channel variations to prevent equalized degradation. It is known that pilot tones can be applied to extract the channel variations. Getting accurate CSI, the system must increase the number of pilot tones, but it also reduces the data rate. The possible solution is to use the scattered pilots to balance the accurate CSI and data rate. The 2-D methods [9], [10] have been developed for SISO-OFDM applications. However, most WLANs do not include any scattered pilot, and the number of pilots is also much smaller than that of data carriers (e.g., IEEE 802.11 a/g/n and Hiper LAN). Due to the aforesaid limitations, all data carriers should be adopted to ensure accurate estimation of channel variations, namely, virtual pilots.

C. Performance Evolution

The parameters of the 4 x 4 MIMO-OFDM system employed are as follows: FFT size is 64, the cyclic prefix (CP) is 16 long, system bandwidth is 20 MHz, and, carrier frequency is 2.4 GHz. To ensure the effectiveness of the proposed method, each packet length is set to 1024 bytes. The Jakes method is used to generate time-varying effects during simulations. The Doppler shifts are set to 133 Hz (speed, 60 km/h) and 266 Hz (speed, 120 km/h). Frequency synchronization is performed to compensate for the frequency shift. The amplitude and phase of channel change significantly at high Doppler shift. Fig. 6 displays the bit-error rate (BER) and packet-error rate (PER) of the 4 x 4 MIMO-OFDM system with and without the Proposed adaptive FD-CE. In "one-shot" legend refers to the case when the proposed adaptive channel estimator is not applied. Obviously, the degradation in BER and PER is significant without proper channel tracking in time-varying fading. Simulations also indicate the effectiveness of the proposed adaptive FD-CE that performs well at 28–30 dB SNR for 64-QAM modulation without any irreducible error floor. Thus, this study can be widely applied to time-varying fading.

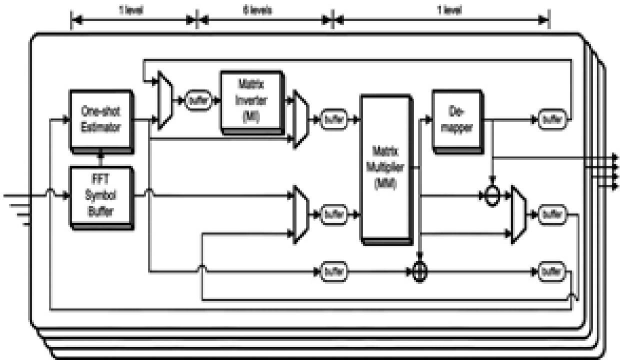

Fig. 2. Architecture of the adaptive FD-CE.

II. ARCHITECTURE

a. Proposed Architecture

Fig. 2 shows the architecture of the proposed adaptive FD-CE that has four major modules: 1) a one-shot estimator; 2) matrix multiplier (MM); 3) matrix inverter (MI); and 4) demapper. The adaptive FD-CE is pipelined to eight levels since the latency of the MI is long. The one-shot estimator is adopted to measure an initial CSI obtained from training symbols (long preambles) [18], and then updated by means of a feedback mechanism. The de-mapper outputs the point of QAM constellation that has the minimum distance to its input. The key issue of implementations is to build efficient architectures for matrix operations, where the functions of MM and MI are discussed as follows.

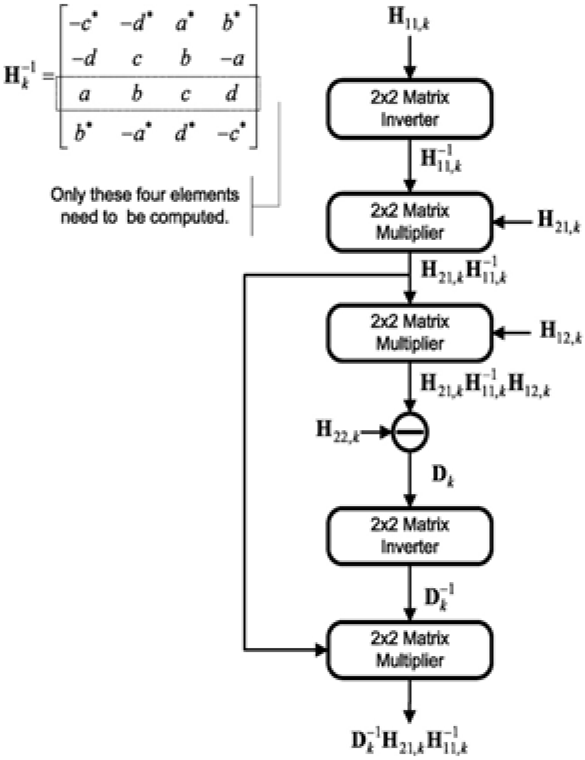

Fig. 3. Flowchart of matrix inversion

They are all Alamouti-like matrices. Fig. 4 shows the architectures, where four complex multipliers and two complex adders are needed in a 2x2 matrix multiplier. Fig. 4 shows the architecture of the 2 x 2 matrix inverter consisting of four square units, three adders, and four dividers. The inverse of a 2 x 2 Alamouti matrix is still an Alamouti matrix [14]. Notably, only half of the Alamouti-like matrix must be computed the other half can be derived from the first half via simple sign-flipping operations. This characteristic is extremely useful as it can be exploited to derive an efficient architecture for implementation.

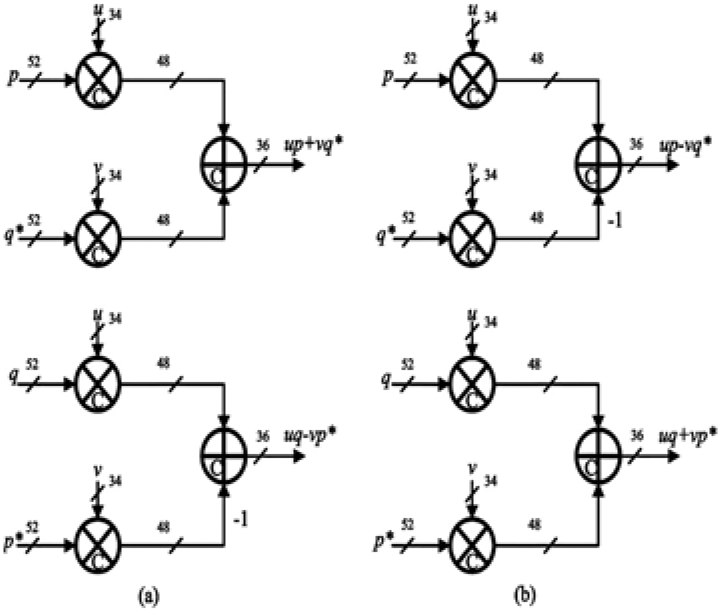

Fig. 4. Architecture of MI.

CONCLUSION

This paper presents an adaptive FD-CE that measures channel variations and prevents performance loss in time-varying frequency-selective fading. Without both specific formats and scattered pilots, all data carriers can be utilized to ensure accurate estimation of channel variations, namely, virtual pilots. Moreover, the proposed FD-CE utilizes the property of the Alamouti-like matrix to decrease the implementation cost of complex operators.

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