A simple channel tracking scheme using deductive combining for MIMO-OFDM WLANs

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Abstract: This letter proposes a simple tracking scheme for time-varying channels of IEEE 802.11 based MIMO-OFDM wireless LANs. The scheme combines a tentative channel estimate derived from a transmitted symbol replica with the channel estimate used to generate the replica. The proposed scheme requires no prior knowledge on the statistics of the channel and instead uses a deductive approach to calculate weights to combine the channel estimates. The numerical results show the proposed scheme performs 1.0 dB CNR gain at FER of 10^{-2} over the conventional scheme for 3×3 MIMO and 64QAM when receiver velocity is 4 km/h.

Keywords: MIMO, OFDM, channel estimation, channel tracking, wireless local area networks, IEEE 802.11

Classification: Wireless Communication Technologies

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1 Introduction

Mobile traffic offloading is an important use case of wireless LANs (WLANs). The WLANs specified in IEEE 802.11 support spatial multiplexing with orthogonal frequency division multiplexing (OFDM) (called multiple-input multiple-output (MIMO)-OFDM) for throughput enhancement. In offloading scenarios, channel variation due to terminal mobility is not negligible; therefore, a channel tracking function is important.

The requirements for channel tracking schemes of 802.11 WLANs are quite severe. First, scattered pilot symbols for channel estimation within a frame [1] are incompatible with the 802.11 format. Second, channel statistical information cannot be referred to and thus Kalman filter approaches [2, 3] are not applicable. Third, the processing delay must be short enough to ensure the response of an acknowledgment in a small interval after an end of data reception as specified by 802.11. This means a receiver cannot use interpolation of channel estimates in time domain (i.e., a 2D-MMSE approach [4]).

Previously, the authors have proposed a channel tracking scheme that meets all these requirements [5]. Instead of pilot symbols, the scheme uses replicas of recently transmitted symbols to estimate the channel without using channel statistical information and without increasing decoding delay.

On the basis of the previous work, in this letter we propose an improved channel tracking scheme that utilizes not only the replicas of recent symbols but also all replicas by combining channel estimates derived by the replicas and the channel estimates used to make them.

2 System model of MIMO-OFDM transceiver

Fig. 1 shows a block diagram of the $K \times M$ frame-based MIMO-OFDM transceiver discussed in this letter. Each OFDM symbol comprises I subcarriers. The receiver detects the transmitted (Tx) symbols from the received (Rx) symbols using the MIMO channel estimate.

An $M \times K$ channel estimate matrix for the i -th subcarrier at the c -th *block* is defined as $\hat{\mathbf{H}}(c, i)$. The *block* is a time unit and consists of K OFDM symbols. The element of $\hat{\mathbf{H}}(c, i)$ at the m -th row and the k -th column is defined as $\hat{h}(m, k, c, i)$. At the head of each frame, the receiver obtains the initial channel estimate $\hat{\mathbf{H}}(0, i)$ by using the symbols in the preamble. To mitigate the influence of the channel variation within a frame, the receiver updates the channel estimates of all subcarriers at every *block* using replicas of Tx symbols.

Fig. 1. Transceiver block diagram of MIMO-OFDM WLAN systems.

3 Conventional channel tracking scheme

This section outlines the conventional channel tracking scheme [5]. Let denote the Rx symbol in the c -th block for subcarrier i as

$$\mathbf{R}(c, i) = \mathbf{H}(c, i)\mathbf{T}(c, i) + \mathbf{N}(c, i), \quad (1)$$

where $\mathbf{R}(c, i)$, $\mathbf{H}(c, i)$, $\mathbf{T}(c, i)$ and $\mathbf{N}(c, i)$ denote an $M \times K$ Rx symbol matrix which is a concatenation of K sets of an $M \times 1$ Rx symbol vector, an $M \times K$ channel matrix, a $K \times K$ Tx symbol matrix defined in the reference [5] and an $M \times K$ additive white Gaussian noise matrix, respectively. The receiver demodulate data from the Rx symbol vector by applying $\hat{\mathbf{H}}(c, i)$, i.e., the estimate of $\mathbf{H}(c, i)$.

At every block, the channel matrix of the tentative estimate $\hat{\mathbf{H}}_{\text{ten}}(c, i)$ is derived as follows:

$$\hat{\mathbf{H}}_{\text{ten}}(c, i) = \mathbf{R}(c, i)(\mathbf{T}_{\text{rep}}(c, i))^{-1} = \mathbf{H}(c, i) + \mathbf{N}(c, i)(\mathbf{T}_{\text{rep}}(c, i))^{-1}, \quad (2)$$

where $\mathbf{T}_{\text{rep}}(c, i)$ is the replica matrix of $\mathbf{T}(c, i)$ defined in Fig. 4 of the reference [5] (called “replica matrix” hereafter) and $(\cdot)^{-1}$ is an inverse matrix operator. When $(\mathbf{T}_{\text{rep}}(c, i))^{-1}$ does not exist, Eq. (2) is not calculated. When the condition

$$\sum_{b=c_{\text{St}}(k, i)}^c w(k, b, i) \geq \alpha \cdot \text{Ave}[|\hat{h}_{\text{ten}}(m, k, b, i)|^2]_{b=c_{\text{St}}(k, i)}^c / \sigma^2 \quad (3)$$

where

$$w(k, b, i) = |\hat{h}_{\text{ten}}(m, k, b, i)|^2 / \left(\sigma^2 \sum_{l=1}^K |t'_{\text{rep}}(l, k, b, i)|^2 \right) \quad (4)$$

is satisfied, the channel estimate $\hat{h}(m, k, c, i)$ is updated as Eq. (5).

$$\hat{h}(m, k, c, i) = \sum_{b=c_{\text{St}}(k, i)}^c (w(k, b, i) \hat{h}_{\text{ten}}(m, k, b, i)) / \sum_{b=c_{\text{St}}(k, i)}^c w(k, b, i), \quad (5)$$

where $w(k, b, i)$, $c_{\text{St}}(k, i)$, α , $\text{Ave}[\cdot]$, $\hat{h}_{\text{ten}}(m, k, b, i)$, σ^2 and $t'_{\text{rep}}(l, k, b, i)$ are the combining weight for $\hat{h}_{\text{ten}}(m, k, b, i)$, the block number next to the previous update of the channel estimate, the preamble to the data symbol power ratio, an average operator, the tentative estimate corresponding to $\hat{h}(m, k, b, i)$, the averaged noise

power per element of $\mathbf{N}(c, i)$, and the element of $(\mathbf{T}_{\text{rep}}(b, i))^{-1}$ at the l -th row and the k -th column, respectively. If the condition Eq. (3) does not stand, then the previous estimate remains as the current estimate ($\hat{h}(m, k, c, i) = \hat{h}(m, k, c - 1, i)$).

The details of the signal processing are presented in Section 3 of the reference [5]. Due to the inherent randomness of the replica matrix, the estimation error of the tentative estimate caused by noise is almost always larger than that of the initial estimate. To improve estimation accuracy, the receiver combines tentative estimates obtained at different *blocks* based on an *approximate* maximum ratio combining (MRC) in Eq. (5). To evaluate channel estimation accuracy, the term “an approximate SNR” (called “a-SNR” in this letter) is introduced. It is defined as the power ratio of the channel estimate over the mean estimation error caused by the noise. It is assumed that the a-SNR of the combined estimate is derived as the summation of the a-SNRs of the tentative estimates which are the combining weights defined in Eq. (4). As Eq. (3) represents, when the a-SNR of the combined estimate becomes greater than that of the averaged channel estimate at the *blocks* $c_{\text{st}}(k, i)$ to c if the preambles were used, the combined estimate is used as the current estimate.

4 Proposed channel tracking scheme

The conventional scheme does not reflect the tentative estimates until the condition of Eq. (3) is satisfied. And, at the update, the tentative estimates based on only recent *blocks* replaces the previous estimate and discards information of the past *blocks* including the preamble. To address these issues, the proposed scheme revises the combining calculation in Eq. (5) to incorporate tentative and previous estimates at every *block* whenever a tentative estimate is derived.

$$\hat{h}(m, k, c, i) = \frac{v(k, c, i)\hat{h}(m, k, c - 1, i) + w(k, c, i)\hat{h}_{\text{ten}}(m, k, c, i)}{v(k, c, i) + w(k, c, i)}, \quad (6)$$

where $w(k, c, i)$ is defined in Eq. (4) and $v(k, c, i)$ is the combining weight for the previous estimate, as will be discussed later and defined in Eq. (8). If the tentative estimate is not derived, the previous estimate remains as the current estimate ($\hat{h}(m, k, c, i) = \hat{h}(m, k, c - 1, i)$.) Fig. 2 shows examples of the signal processing for the conventional and proposed schemes. Since the receiver cannot know the statistical information of channel variation and generates the previous estimate by recursive combining in Eq. (6), the combining weight $v(k, c, i)$, i.e., the a-SNR of the previous estimate, cannot be derived precisely. Instead, the proposed scheme employs a deductive approach.

We first set a requirement for a-SNR of the combined estimate in Eq. (6) (i.e., $v(k, c, i) + w(k, c, i)$) in the same manner as the conventional scheme in Eq. (3).

$$v(k, c, i) + w(k, c, i) \geq \alpha \cdot \text{Ave}[|\hat{h}(m, k, c - 1, i)|^2, |\hat{h}_{\text{ten}}(m, k, c, i)|^2]/\sigma^2. \quad (7)$$

Since Eq. (7) does not provide an exact $v(k, c, i)$, we introduce two additional assumptions. First, the relative value of $w(k, c, i)$ to $v(k, c, i)$ is maximized to fully utilize freshness of the tentative estimate. This corresponds to set the equal sign in Eq. (7). Second, Eq. (7) must stand regardless of the combining weight $w(k, c, i)$. As seen in Eq. (4), when the replica matrix generate extremely large noise

Fig. 2. Example of signal processing for channel tracking schemes:
 (a) Conventional scheme/(b) Proposed scheme.

enhancement, the combining weight $w(k, c, i)$ is asymptotically zero. This means that Eq. (7) must hold even when $w(k, c, i) = 0$. By applying these two assumptions to Eq. (7), the combining weight $v(k, c, i)$ is derived.

$$v(k, c, i) = \alpha \cdot \text{Ave}[|\hat{h}(m, k, c - 1, i)|^2, |\hat{h}_{\text{ten}}(m, k, c, i)|^2] / \sigma^2. \quad (8)$$

As well as the previous scheme (in Eq. (11) of the reference [5]), it is assumed that the powers of the tentative and previous estimates are approximately the same.

$$\text{Ave}[|\hat{h}(m, k, c - 1, i)|^2, |\hat{h}_{\text{ten}}(m, k, c, i)|^2] = |\hat{h}_{\text{ten}}(m, k, c, i)|^2. \quad (9)$$

By using Eq. (9), the relative values of $v'(k, c, i)$ in Eq. (10) and $w'(k, c, i)$ in Eq. (6) of the reference [5] can be used as the alternatives of $v(k, c, i)$ and $w(k, c, i)$.

$$v'(k, c, i) = v(k, c, i) / (|\hat{h}_{\text{ten}}(m, k, c, i)|^2 / \sigma^2) = \alpha. \quad (10)$$

As a result, the combining weight $v'(k, c, i)$ becomes a fixed value and thus no additional computational complexity is needed to derive it.

5 FER performance evaluation

The simulation parameters for frame error rate (FER) evaluation were the same as those of the reference [5]. The major parameters and settings were a 20 MHz channel, a 64QAM modulation scheme, a 3/4 coding rate, and maximum likelihood signal detection based on the QRD-M algorithm. The receiver processing delay (T_{delay} in Fig. 2) was set to two OFDM symbols. The channel model was an uncorrelated Rayleigh fading one with 50 ns delay spread. The data portion of a frame comprised eight subframes. The FER was measured as a subframe error rate.

Fig. 3 shows the FER improvement with both the conventional and the proposed channel tracking schemes. Even when the receiver moves with 4 km/h, the systems with both the tracking schemes outperform the benchmark system of a

Fig. 3. FER performances of conventional and proposed schemes.

fixed (0 km/h) receiver but without a channel tracking scheme. At FER of 10^{-2} , the proposed scheme has 1.0 dB gain of required CNR over the conventional scheme. This gain comes from the improved channel estimation accuracy by incorporating previous estimates in combining and updating channel estimates more frequently. When the mobility of the receiver is higher (8 km/h), FER performance degrades, but still the system with the propose scheme outperforms the system with the conventional scheme and the benchmark system at FER of 10^{-2} .

6 Conclusion

This letter proposed a simple channel tracking scheme suitable for MIMO-OFDM WLANs based on IEEE 802.11. The scheme combines a tentative channel estimate derived from a transmitted symbol replica with the channel estimate used to generate the replica to track the channel variation. Comparing the required CNR at FER of 10^{-2} , the proposed scheme performs 1.0 dB better than the conventional scheme. This performance improvement will contribute to extending high capacity areas in traffic offloading using WLANs.

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