A Joint Channel Estimation and Unequal Error Protection Scheme for Image Transmission in Wireless OFDM Systems

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***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) modulation, adopted by the Digital Video Broadcasting (DVB-T) standard, has been recognized for its good performance for high data rate wireless communications. Therefore, the study of the robust transmission of multimedia data over OFDM systems has attracted extensive research interests. In the past, channel estimation, which is an important aspect in OFDM systems, has not been exploited for multimedia transmission. When using the block training based channel estimation, OFDM data blocks experience unequal decoding error rate due to the imprecision of channel estimation. We use this property to provide unequal error protection(UEP) for transmission of SPIHT coded images. Compared with the systems using pilot training channel estimation schemes, which are recommended in the DVB-T standard, the proposed scheme improves the PSNR of reconstructed images by up to 2dB.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) modulation has been adopted by many wireless multimedia transmission standards, such as digital audio broadcasting (DAB) and digital video broadcasting (DVB-T) [1][2], due to its desirable properties. The OFDM modulation can transform frequency selective fading channel into a set of parallel flat fading subchannels, facilitating high data rate transmission without employing complex equalization schemes.

Channel estimation, required by coherent signal detection, has a significant impact on the performance of the OFDM receivers. The channel estimation techniques can be divided into two categories: *blind methods*, where channel information is estimated directly from data signals, and *training methods*, where channel information is estimated from training sequences or pilot symbols that are known by the receiver. Compared with blind methods, training methods usually provide more accurate estimation at the expense of bandwidth overhead to transmit training data[3].

The training methods can be further divided into two groups based on the arrangement of the training symbols. In case of the first group, the pilot training methods, the pilot symbols are inserted among the data symbols and the path gains of the subchannels are estimated using interpolation. The second popular training scheme is the block training method, where data and training symbols are transmitted in separate OFDM blocks. Currently, the DVB-T standards recommend pilot training techniques for channel estimation.

When using block training schemes, the channel estimation error may vary considerably as a function of the location of the data blocks with respect to the training blocks. This will result in a periodic variation of the decoding error rates for different OFDM blocks. On the other hand, the pilot training techniques can eliminate this variation, and therefore all OFDM data blocks experience approximately the same error rate. Since the error rate of pilot training schemes is higher than the lowest error rate which can be achieved by block training methods, the block training methods provide the opportunity to protect the data with high importance/priority by transmitting them at the positions where the error rate is low, while transmitting less important data at the positions where the error rates are higher. As a consequence, the pilot training methods are more suitable for generic data transmission, but they may not be suitable for multimedia data transmission.

In this paper, we propose a scheme that uses the error rate variation of the block training method to provide Unequal Error Protection (UEP) for the transmission of images over wireless channels. To the best of our knowledge, the properties of channel estimation have not been exploited for the transmission of multimedia data. Furthermore, we compare the quality of the delivered images using pilot training scheme and the proposed block training UEP scheme.

The rest of the paper is organized as follows. In Section II, we introduce the OFDM system and briefly review the block training and pilot training channel estimation methods. In Section III, the unequal error property of block training channel estimation schemes is investigated. The UEP scheme for the transmission of progressively coded images is described in Section IV, followed by the simulation results in Section V and the conclusion in Section VI.

II. Channel Estimation in OFDM Systems

A block diagram of an OFDM transmitter and receiver is illustrated in Figure 1. The input data are first arranged into blocks and mapped to a set of complex constellation points $\{X_{1,k}, \cdots, X_{N,k}\}$, where k is the index of the OFDM blocks and N is the block length. Modulation is implemented as the N-point Inverse Discrete Fourier Transform (IDFT), followed by cyclic prefix insertion and parallel-to-serial (P/S) conversion. Since the cyclic prefix eliminates the interference between both adjacent blocks and adjacent symbols, the frequency selective channel becomes a set of flat fading subchannels. In this case, the received signal can be expressed as:

$$Y_{i,k} = H_{i,k}X_{i,k} + w_{i,k}, \quad i = 1, \cdots, N \tag{1}$$

where $H_{i,k}$ represents the channel gain of the i^{th} subchannel in the k^{th} block, $Y_{i,k}$ is the output after Discrete Fourier Transform (DFT) at the receiver, and $w_{i,k}$ is additive white Gaussian noise with mean zero and variance σ^2.

After the DFT, the one-tap equalizer takes the estimated channel parameters $\hat{H}_{i,k}$ and the received signals $Y_{i,k}$, and produces the estimates

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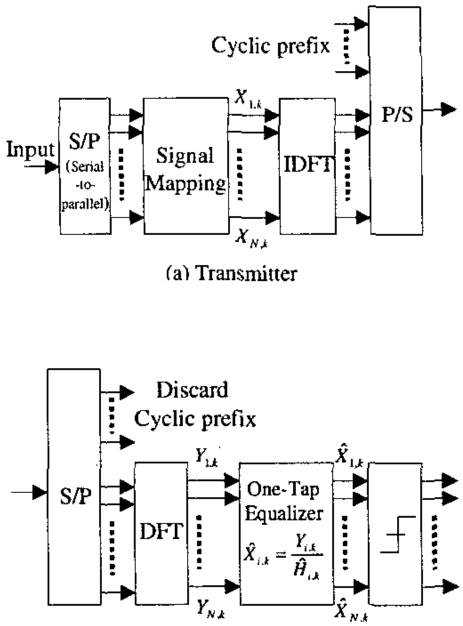

(a) Transmitter

(b) Receiver

Fig. 1. High Level Diagram of OFDM Systems

of the transmitted signals, $\hat{X}_{i,k}$. Mathematically, it can be written as

$$\hat{X}_{i,k} = \frac{Y_{i,k}}{\hat{H}_{i,k}} = \frac{H_{i,k}}{\hat{H}_{i,k}} X_{i,k} + \frac{w_{i,k}}{\hat{H}_{i,k}}. \quad (2)$$

It is clear that the channel estimation error plays an important role in the overall performance of the communication system.

Figure 2(a) shows the training pattern of the block training scheme. In this case, an OFDM block is either a training block or a data block. All the symbols in the training blocks are known by the receiver and used to estimate the channel parameters for the subchannels. When decoding a data block, the receiver uses the channel information estimated from nearby training blocks. Since the channel is time-varying, the data blocks that are closer to the training blocks are decoded using more accurate channel information, and experience less errors. On the other hand, data blocks that are farther from the training block and decoded using less accurate channel information will have higher error rates.

One example training pattern for the pilot training scheme is illustrated in Figure 2(b). When using this method, training pilots are inserted in OFDM blocks and used to help the receiver to obtain temporal estimates of the subchannel gains at the pilot symbol locations. The channel parameters for other subchannels are then obtained through interpolation. To simplify the analysis, we only focus on frequency domain interpolation in this paper. Training pilots are inserted in every OFDM block and interpolation is applied only within the block.

III. Unequal Error Property of Block-Training Based Channel Estimation Schemes

As discussed in the previous section, there is a periodic variation in the bit error rate when using block training channel estimation techniques. We use M to represent the number of data blocks between two

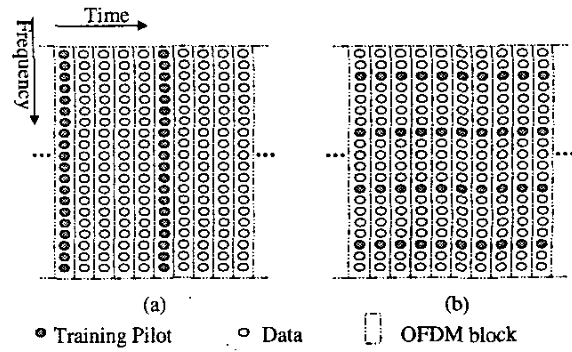

Fig. 2. Typical Training Patterns for coherent channel estimation

training blocks, and $\{p(k), k = 1, 2, \cdots, M\}$ to represent the average bit error rate (BER) of the k^{th} data block after the training block. In this work, each data block is assumed to be decoded using the channel parameters estimated from the nearest previous training block. The typical values of $p(k)$ are shown in Figure 3 for Typical Urban(TU) delay profile[4] (see Figure 4) with different Doppler frequency and channel signal-to-noise ratio (SNR). The average error rate of pilot training channel estimation schemes, denoted by b_p, is represented by straight lines in Figure 3.

The comparisons in Figure 3 lead to three observations. First, the lowest error rate which can be achieved by using block training is lower than the average error rate of pilot training, i.e. $p(1) < b_p$. This property indicates that the pilot training has the potential to provide stronger protection for certain potion of the data. Second, when channel changes fast (high Doppler frequency), the worst error rate of block training is much larger than b_p. This is because block-training cannot track the changes in channel conditions as efficiently as the pilot training scheme. Third, pilot training does not perform well at lower channel SNR, while block training is more robust to channel noise.

For generic data transmission, the block training has advantages of combating frequency selective fading, and pilot training has advantages of tracking the temporal variation of the channel. In the past, these two training schemes are not compared for the transmission of multimedia bit stream. In the following sections, we propose an UEP scheme for the transmission of multimedia bit stream in OFDM systems using block training channel estimation techniques, and then compare the proposed scheme with the pilot training which do not have the unequal error property.

IV. Priority Transmission

When using block training, UEP can be achieved by transmitting the data with high priority or importance near the training blocks. Such an UEP scheme shall be called *priority transmission* (PT). The PT scheme can be used in any general multimedia transmission scenario. In this paper, we provide a particular example using SPIHT [5] coded images.

The output of the SPIHT encoder is progressive such that wherever the transmission stops or an error occurs, the received data can be used to reconstruct an image with certain quality. The more data is received, the better the quality of the reconstructed images is. The SPIHT bitstream can be divided into substreams, and each of them contains the information of one bit plane . Figure 5 illustrates two ways to transmit the SPIHT bitstream in OFDM systems, where the substream with

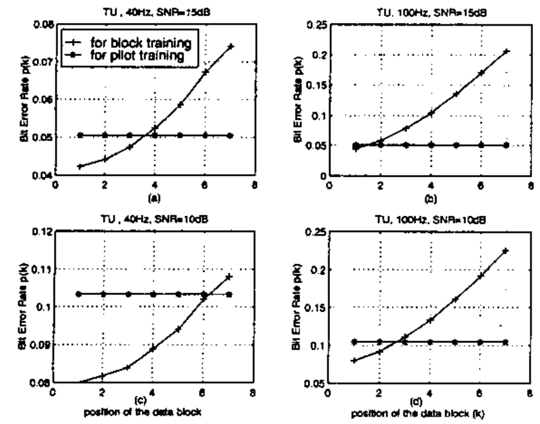

Fig. 3. Comparison of Averaged bit error rate of OFDM data blocks between block training and pilot training. (a) TU delay profile, Doppler frequency 40Hz, channel SNR=15dB; (b) TU delay profile, Doppler frequency 100Hz, channel SNR=15dB; (c) TU delay profile, Doppler frequency 40Hz, channel SNR=10dB (d) TU delay profile, Doppler frequency 100Hz, channel SNR=10dB

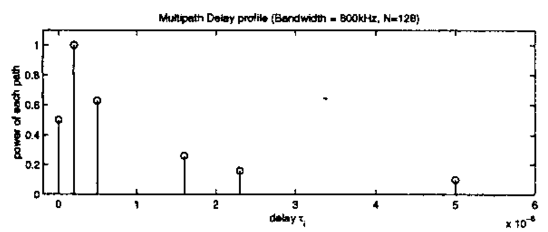

Fig. 4. Typical Urban (TU) Delay profile, where τ_i is the delay of the ith path in Multipath Rayleigh fading channel model.

higher index is considered to be more important to the decoder. Although the bits within one bit plane also have different importance [6], we do not apply UEP within a bit plane.

As shown in the upper part of Figure 5, in the regular transmission scenario, the data is sent in its natural order and the unequal error property of the channel is not exploited. When the priority transmission is implemented, the transmitter rearranges the input data according to their importance in such a way that data with higher importance are transmitted closer to the training blocks. As illustrated in the lower part of Figure 5, the most important bit plane is always transmitted immediately after the training blocks. Since the training pattern usually does not change during the transmission, only a small amount of side information on reordering needs to be sent to the receiver at the beginning of transmission such that the decoder can assemble the received data back to the original order. In addition, the delay introduced by PT can be easily limited by rearranging the transmission order within the delay constraint.

There are many other ways to provide UEP to the transmission of progressive images. One of the most popular methods is to apply forward error correction (FEC) codes with different coding rates according to the importance of data [6][7]. Compared with the FEC based methods, the proposed scheme has the advantages of not introducing redundancy to transmission and easy implementation. In addition, the proposed scheme can work together with FEC based methods when

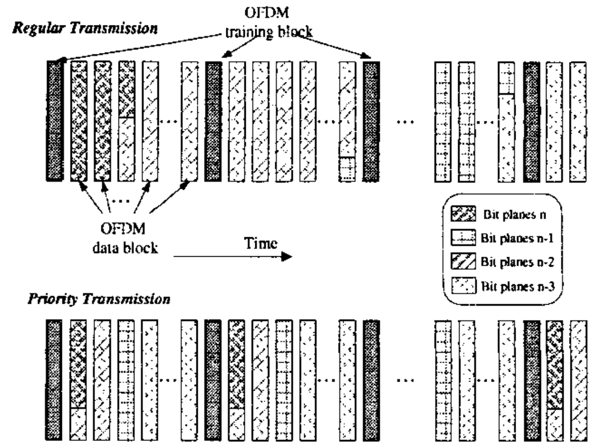

Fig. 5. Priority Transmission for SPIHT encoded Images

the coding rates are chosen considering both the variation of $p(k)$ and the importance of data.

V. Simulation Results

The transmission of SPIHT encoded images was simulated in OFDM systems for different channel SNRs. The input was the 512 by 512 Lena image source encoded at data rate of 1 bit per pixel (bpp). The OFDM block length was 128 with a 16 symbol long cyclic prefix, and the bandwidth was 800kHz. QPSK modulation was used for all subchannels. Typical urban delay profile (Figure 4) with Doppler frequency of 40Hz and 100Hz was used to simulate the multi-path fading channel. The channel coding was chosen to be a (28,14) punctured/shortened Reed-Solomon code.

Two image transmission systems were simulated. In the first system, the block training channel estimation technique was used together with the PT scheme described in Section IV. The block training was implemented by sending one training block in every 8 OFDM blocks. The second system employed pilot training channel estimation by sending one training pilot in every 8 subchannels in each OFDM block, so the two schemes send the same amount of training data. The channel estimation techniques proposed in [3] were used, and time-domain interpolation was not applied to either scheme.

The average peak-signal-to-noise-ratio (PSNR) of the reconstructed images for different channel SNR is shown in Figure 6 and Figure 7. When the Doppler frequency is 40Hz, the system using block training with PT performs better than the system using pilot training when channel SNR is less than 23dB. For higher channel SNR, the pilot training performs better. Since training symbols are sent at every subchannel when using block training and are sent only at a subset of subchannels when using pilot training, the block training can estimate the frequency selective wireless fading channel better than pilot training in the presence of strong channel noise. This is the reason why block training has better performance in low and moderate channel SNR region. However, block training cannot track the changes of the channel between two training blocks, which results in performance degradation in the high channel SNR region. In case of 40Hz Doppler frequency, the performance curves intersect at 23dB, while in case of 100Hz Doppler frequency, the intersection is at 18dB, which verifies our argument.

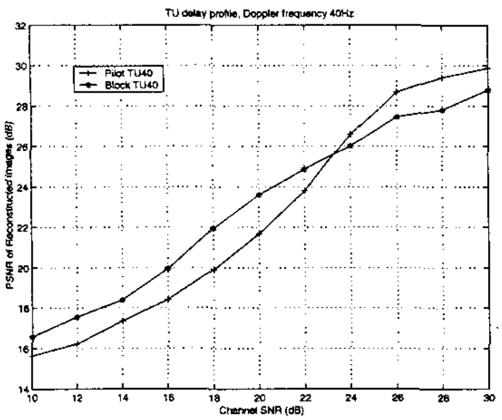

Fig. 6. Performance comparison for Doppler frequency 40Hz

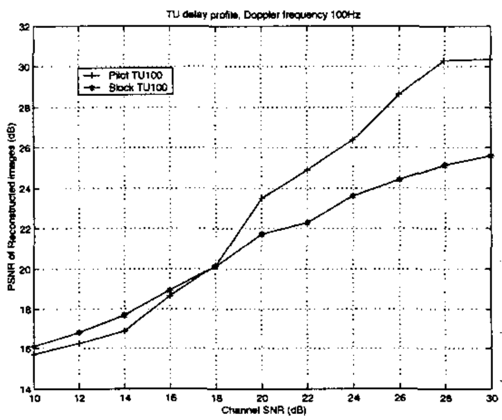

Fig. 7. Performance comparison for Doppler frequency 100Hz

The above performance curves show that the proposed system can achieve performance gain up to 2dB in the moderate channel SNR region, where the most realistic wireless systems operate. Figure 8 shows the reconstructed images when the channel SNR is 20dB. The proposed scheme also achieves better perceptual quality.

(a) A reconstructed image in system using pilot training

(b) A reconstructed image in system using block training and PT

Fig. 8. Reconstructed Images when channel SNR = 20dB, Doppler frequency = 40dB

VI. Conclusion

This paper proposed a scheme to exploit the error rate variation of the block training channel estimation methods to provide UEP for multimedia transmission. The most important advantage of this scheme is that it does not require any bandwidth overhead or any additional redundancy. Since DVB-T standards recommend pilot training that can eliminated the variation of the error rates, the proposed scheme is compared with the systems using pilot training for different channel SNR and Doppler frequency. A performance gain of up to 2dB in the PSNR of the reconstructed images is achieved at the moderate channel SNR region.

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