A JOINT CHANNEL ESTIMATION AND UNEQUAL ERROR PROTECTION SCHEME FOR VIDEO TRANSMISSION IN OFDM SYSTEMS

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ABSTRACT

OFDM modulation, which has been adopted by the Digital Video Broadcasting (DVB-T) standard in Europe, has been recognized for its good performance for high data rate wireless communications. Therefore, the study of the robust transmission of multimedia data over the OFDM systems has attracted extensive research interest. 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 schemes, there exists a periodic variation of the error rates due to the channel estimation imprecision. We use this property to provide unequal error protection(UEP) for the video transmission. Compared with systems using pilot-training based channel estimation schemes, which are recommended in the DVB-T standard, a performance gain of about 2dB in the PSNR of the reconstructed images is achieved.

1. INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) modulation can largely eliminate the effects of intersymbol interference(ISI) for high transmission data rates in very dispersive environments[1], and has been adopted by the digital video broadcasting (DVB-T) standards in Europe [2]. Channel estimation is an important module in the OFDM receiver. The imprecision of the channel information estimated at the receiver, as well as the noise and fading in the wireless channel, cause decoding errors.

Currently, the DVB-T standards recommend using pilot-training to perform channel estimation. When using the pilot-training, the OFDM data blocks have the same averaged error rate. However, when using block-training based channel estimation schemes, there exists a periodic variation of the error rates due to the channel estimation imprecision. The averaged error rate of pilot-based channel estimation schemes is higher than the lowest error rate which can be achieved by using block training methods. Therefore, the pilot training is suitable for the generic data transmission, where all data have the same priority, but may not be suitable for the multimedia bitstream that usually contains several types of data with different importance. In the past, channel estimation has not been exploit for the transmission of multimedia data. We propose to use the variation of the error rate from block-training to provide UEP for the video transmission by transmitting the data with high importance/priority at the positions where the error rates are low. We shall compare the quality of the delivered video using pilot-training based schemes and the proposed block-based UEP scheme.

In this paper, the channel estimation schemes in OFDM systems are reviewed in Section 2. An UEP scheme for H.263 video transmission is proposed in Section 3, followed by the simulation results in Section 4 and the conclusion in Section 5.

2. CHANNEL ESTIMATION IN OFDM SYSTEMS

A high level diagram of OFDM modulation is shown in Figure 1. At the transmitter, the input data are first arranged into blocks through a serial-to-parallel (S/P) converter, and then they are mapped to a set of complex constellation points $\{X_{1,k}, \cdots, X_{N,k}\}$, which shall be called the OFDM data block, where k is the index of the blocks. The modulation is implemented as the N-point inverse discrete Fourier transform (IDFT), followed by cyclic prefix insertions and a parallel-to-serial (P/S) converter. The purpose of the cyclic prefix is to eliminate the ISI between adjacent blocks. At the receiver, a serial-to-parallel (S/P) converter is used followed by the discrete Fourier transform (DFT). The entire channel can be looked at as a set of subchannels[3], i.e.

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

where $H_{i,k}$ and $\Gamma_{i,k}$ represent the channel frequency response and the channel noise of the i^{th} subchannel in the k^{th} block respectively. At the OFDM receiver, it is essential to estimate the channel parameters, $\{H_{i,k}\}$, which are used in the one-tap equalizer.

Channel estimation techniques can be divided into two categories: *blind methods*, where channel information is estimated directly from data signals, and *coherent methods*, where channel information is estimated from training sequences/pilots that are known by the receiver. The coherent methods can usually get more accurate estimation than the blind methods at the expense of additional bandwidth used to transmit training data[4]. Two typical patterns of the training data used by the coherent methods are illustrated in Figure 2.

When using the block training pattern showed in Figure 2(a), an OFDM block is either a training block or a data block. All the data in the training blocks are known by the receiver and used to estimate the channel parameters for all 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 and therefore are decoded using more accurate channel information experience less errors than other data blocks that are further from the training block and decoded using less accurate channel information.

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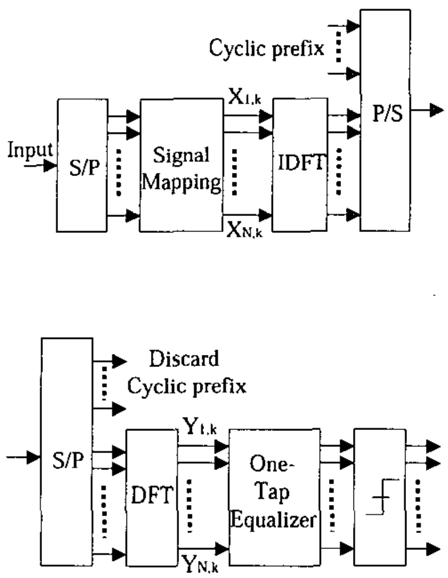


(b) Receiver

Fig. 1. High Level Diagram of OFDM Systems

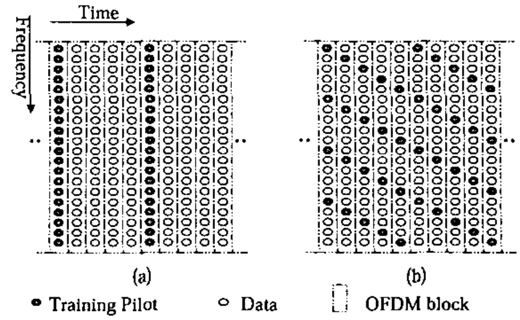


Fig. 2. (a)Block training (b)Pilot training

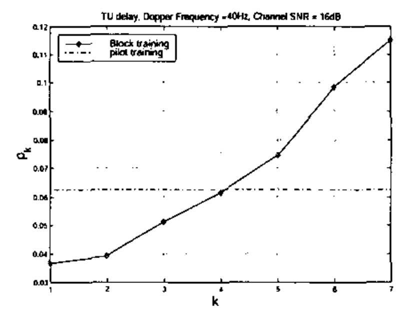


Fig. 3. Averaged error rates of OFDM data blocks when using block training and pilot training

There is a periodic variation of the averaged error rates in the data blocks. Let M denote the number of data blocks between two training blocks, and $p_k, k = 1, 2, \cdots, M$ denote the averaged error rate for the k^{th} data blocks after the training blocks. 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 $\{p_k\}$ is shown in Figure 3 when the channel SNR is 14dB. The system setup is described in Section 4. Since each OFDM block is coded as an Reed-Solomon(RS) codeword, and $\{p_k\}$ represent the RS codeword error rates. In Section 3, we will use the variation of $\{p_k\}$ to provide UEP for the video transmission.

An interlaced pilot training pattern (Figure 2(b)), adopted by DVB-T standards, can eliminate the variation of the averaged error rates. Each OFDM block contains both training pilots and data. The channel parameters used to decode the data are obtained by frequency-domain interpolation from the channel parameters estimated from the training pilots. As illustrated in Figure 3, the averaged error rate of pilot-based channel estimation schemes[4] is higher than the lowest error rate which can be achieved by using the block training. Therefore, pilot training is suitable for the generic data transmission, where all data have the same priority, but may not be suitable for the multimedia bitstream that usually contains several types of data with different importance.

3. 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 a *priority transmission*(PT) scheme. PT can be used to provide UEP in many circumstances, such as scalable video transmission and reliable delivery of keying information in the secure multicast applications. In this section, PT scheme is demonstrated by its application in the transmission of H.263 video bitstream.

A high level diagram of the H.263 video bitstream is shown in Figure 4(a). The Header contains the information describing the coding methods and is essential for the decoding process. Motion vector(MV) information enables the decoder to build a prediction of the current frame based on the frames it has already decoded. DCT coefficients convey the information of the residual, which is the difference between the true values and the predictions. Due to the extensive usage of the variable length coding, transmission errors may cause the decoder to lose synchronization and therefore the effects of the transmission error will propagate[5]. Synchronization marks are inserted to help the decoder to regain synchronization. The data between two synchronization marks can be looked at as a slice[6].

Data Partitioning is an effective method to improve the error resilience of the multimedia data, and is adopted by both H.263++ and MPEG4 [5]. As depicted in Figure 4(b), a Data Partitioning scheme re-organizes the data in such a way that all header information in one slice is first transmitted, followed by all motion vectors in the slice, and finally by all DCT coefficients in the slice. The Header, MV and DCT partitions are separated by *Header marks* and *MV marks*, and are encoded using reversible variable length codes [5]. By allowing resynchronization within the slice and backward decoding when an error occurs, the Data Partitioning scheme reduces the effects of error propagation and improves the robustness of the video transmission[7][5].

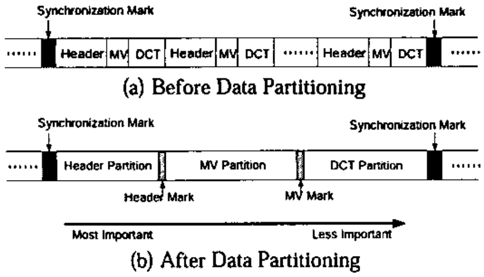


Fig. 4. Structure of the Video bitsteam

With the Data Partitioning scheme, the importance of the data is roughly in the decreasing order within one slice (Figure 4(b)). The header information is more important than the MVs and the DCT coefficients because the whole picture (slice, macroblock (MB) [6]) cannot be decoded without the picture (slice, macroblock) header. The MVs that are used to generate the prediction of the current frame are more important than the DCT coefficients that represent the prediction residual, because the residual is useless without the accurate prediction being made. Therefore, it is desirable to provide different levels of protection to different partitions. We apply the Priority Transmission (PT) scheme after the Data Partitioning in two steps:

1. The number of the macroblocks(MB) in each slice is adjusted in such a way that (1) each slice has roughly the same size, (2) and the slice size is roughly the multiple of the size of the OFDM data blocks.
2. Each slice is divided into smaller units, which have the same size as the OFDM data blocks. As depicted in Figure 5, the transmission order of these units in one slice is rearranged such that the units with higher importance are transmitted at the positions with lower error rates. The units belonging to different slices cannot be mixed.

In the first step, the purpose of making the slice size uniform is to reduce the amount of side information that needed at the receiver. Since the units within one slice are naturally positioned in decreasing order of their importance after the Data Partitioning, the transmission order of those units only depends on the training pattern and the size of the slices. In the proposed scheme, all slices have roughly the same size except the last slice in each picture frame. Therefore, only the side information of the last slice in each picture frame need to be sent in order to enable the receiver to assemble the disordered units.

In addition, PT scheme introduces delay because the receiver cannot decode a slice until all units belonging to this slice are received. However, since the reordering occurs only within one slice, the delay is bounded by the amount of information within one slice.

By matching the importance of the multimedia data to the variation of the channel error rates, PT is an efficient and simple method to provide UEP without introducing large amounts of redundancy and delay. Additionally, PT is compatible with other UEP schemes, which do not exploit the properties of the channel estimation and provide UEP by applying different forward error correction (FEC) codes to the data with different importance.

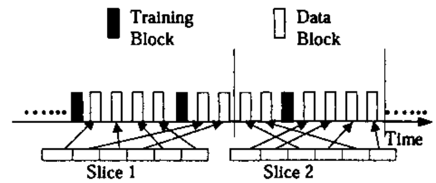


Fig. 5. Priority Transmission Scheme

4. SIMULATION RESULTS

The transmission of H.263 video sequences is simulated in OFDM systems for different channel signal-to-noise ratios. The input is the football video sequence encoded with an averaged data rate of 48kbyte/sec. The OFDM system has 128 subchannels. The bandwidth is 800kHz. QPSK is used for all subchannels. The cyclic prefix has the length of 16 symbols. Typical urban(TU) delay profile[8] with Doppler frequency of 40Hz is used to simulate the multi-path fading channel. Each OFDM block is coded as an RS codeword with the coding rate 1/2.

Two training patterns were chosen. The block training is implemented by sending one training block in every 8 OFDM blocks. The pilot training is implemented by sending one training pilot in every 8 subchannels in each OFDM block. Two schemes send the same amount of training data. The channel estimation techniques proposed in [4] are used. Time-domain interpolation is not applied to either scheme.

Three video transmission systems are compared. System *A* uses block training without Priority Transmission. System *B* uses block training with the Priority Transmission scheme. System *C* uses the pilot training. Data Partitioning is implemented in all of the three systems. The approximate slice size is 1280 bits in the block training based systems, and is 1232 bits in the pilot training based systems. Simulation results are shown in Figure 7 and Figure 6. Figure 7 shows the 12^{th} reconstructed images of the football sequence when the channel SNR is 15dB. Compared with system A and system C, System B has better perceptual quality of the reconstructed images. In addition, the averaged peak-signal-to-noise-ratio (PSNR) of the reconstructed images are shown in Figure 6.

By comparing the performance of system *A* and system *B* where block-training is used, we observe that the performance gain introduced by Priority Transmission is up to 4.5dB at the high channel SNR region. At the low channel SNR region, decoding errors are mainly caused by the noise and fading in the wireless channel and the effects of channel estimation inaccuracy are not apparent. Therefore, the performance gain is an increasing function with the channel SNR.

Additionally, the system using block training and PT scheme (system *B*) performs better than the system using pilot training (system *C*) by up to 2.5dB. This result shows that block training has advantages over pilot training for video transmission, and indicates that the joint design of training pattern and video transmission improves the performance of a multimedia transmission system.

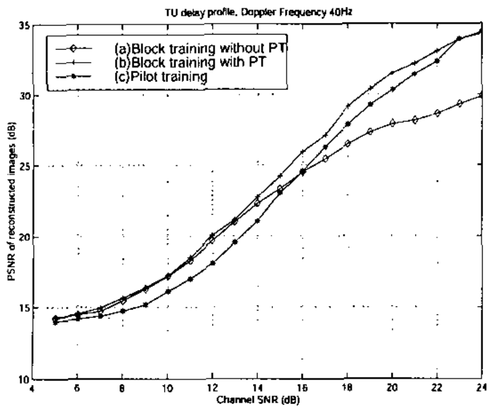
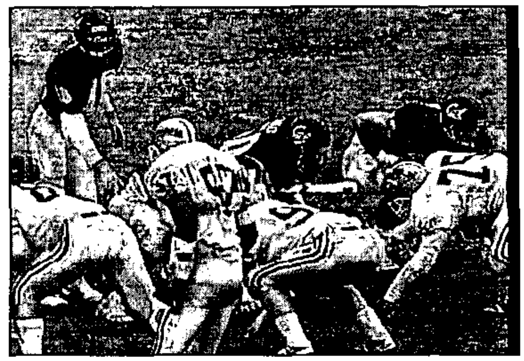
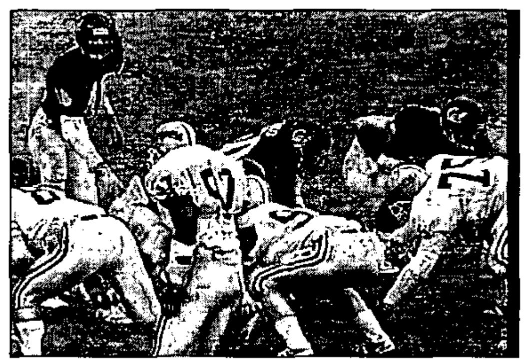


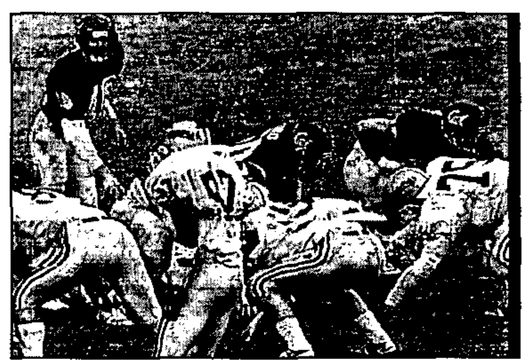
Fig. 6. Performance Comparison



(a) A reconstructed image in System A(block training w/o PT)
Note the blocky distortion near the players



(b) A reconstructed image in System B(block training with PT)
Note: less blocky distortion



(c) A reconstructed image in System C(pilot training)
Note the blocky distorting near the players

Fig. 7. Comparison of the 12th frame of the football sequence

5. CONCLUSION

Since block training causes the periodic variation of averaged error rates in OFDM systems, a joint channel estimation and UEP scheme, called *priority transmission*, is proposed to enhance the robustness of the video transmission. Using the observation that the importance of the data is roughly in decreasing order within one slice after the data partitioning, priority transmission is applied to the H.263 video transmission by transmitting the data with high importance/priority near the training blocks. 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. A performance gain of up to 2.5dB in the PSNR of the reconstructed images is achieved.

6. REFERENCES

[1] J. Chuang and N. Sollenberger, "Beyond 3g: wideband wireless data access based on ofdm and dynamic packet assignment," *IEEE Communications Magazine*, vol. 38, pp. 78–87, July 2000.

[2] "Digital video broadcasting(DVB) framing structure, channel coding and modulation digital terrestrial television (DVB-T)," ETS 300 744, v1.2.1, June 1999.

[3] J. A. C. Bingham, "Multicarrier modulation for data transmission: an idea whose time has come," *IEEE Communication Magzine*, pp. pp5–14, May 1990.

[4] Ye Li, "Pilot-symbol-aided channel estimation for ofdm in wireless sytems," *IEEE Trans. on Vehicular Technology*, vol. 49, no. 4, pp. 1207 –1215, July 2001.

[5] M. Luttrell, J. Villasenor, J.H. Park, and D.S. Park, "A data partitioning-based video coding algorithm for error prone channels," in *Packet Video Workshop'99 Proceedings*, 1999.

[6] "Video coding for low bit rate communication," ITU-T Recommendation H.263, January 1998.

[7] Ming-Ting Sun and Amy R. Reibman, Eds., *Compressed Video over Networks*, Marcel Dekker, 2001.

[8] W. C. Jakes, *Microwave Mobile Communications*, New York: Wiley, 1974.