Feedback Cancellation Based on Partitioned Channel Estimation for T-DMB Repeaters

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***Abstract*— This paper proposes a channel estimation (CE) method to improve the feedback cancellation performance in a terrestrial digital multimedia broadcasting repeater (T-DMBR) as an on-channel repeater (OCR). There is a crucial requirement for an OCR that the isolation between the transmitter and the receiver antennas should be sufficiently secured to prevent an oscillation caused by the feedback due to the antenna coupling. The required isolation, however, may not be satisfied by some physical or technical limitations. In order to overcome these obstacles, undesired feedback caused by the insufficient isolation has to be minimized. Focusing on the demodulation-type OCR we propose a partitioned channel estimation method in the Phase Reference Symbol (PRS) of increasing the number of updates by partitioning the transformed PRS in time domain to enhance the accuracy of CE. Simulation result shows that the feedback canceller incorporating the proposed CE method has a good performance in terms of residual feedback power.**

I. INTRODUCTION

A demand for regional expansion of terrestrial digital multimedia broadcasting (T-DMB) services in Korea has triggered that service coverage should be enlarged without the degradation of service quality. To cope with this need, there may be two approaches. One is the increase of the transmission power at the main transmitter and the other is to raise the number of distributed transmitters or repeaters. The latter has been considered a good solution because it is general that the transmission power of the former is strictly limited by the radio emission regulations [1]. However, the increase of the number of transmitters at sub-stations for multiple-frequency network may make the policy of frequency allocation very complicated, resulting in high cost.

On the other hand, on-channel-repeaters (OCRs), which re-transmit a signal on the same frequency as it receives, possess some advantages of the freedom of transmission power variation and simple frequency allocation [2]. In the use of an OCR, however, there is a crucial requirement that the isolation between the transmitter and the receiver antennas is sufficiently secured to prevent an oscillation caused by the feedback due to the antenna coupling [2]-[5]. Apart from the antenna isolation problem of an OCR, researches on the feedback cancellation have been performed because there are some physical and technical limitations in achieving satisfactory antenna isolation which can be overcome by appropriate feedback cancellation [2]-[5].

There have been two major feedback cancellation schemes for an OCR: an intermediate-frequency (IF) type and a demodulation type. An IF-type OCR eliminates the unwanted feedback signal using an adaptive filter with a replica generated from the output of the repeater [4]. This method is not influenced by the modulation type of the transmitted signal and eliminates the feedback signal in real time but its cancellation performance is dependent upon the accuracy of channel estimation which may suffer from the purity of a reference signal. In addition, there still remains to be a problem where we extract a reference signal for accurate feedback channel estimation. A demodulation-type OCR, on the other hand, enhances the estimation accuracy by the use of pilot-assisted channel estimation at the expense of demodulation delay and hardware complexity [5]. Whether we choose an IF type or a demodulation type for an OCR as a DMB repeater can be determined by considering their trade-offs. This paper focuses on the minimization of residual feedback power in the re-transmitted signal of the repeater and thus deals with the demodulation-type OCR.

There exists a troublesome problem in applying the feedback cancellation technique of the demodulation-type OCR to T-DMB repeaters (T-DMBRs). Since the T-DMB system does not include any pilot symbols except for the Phase Reference Symbol (PRS) which is transmitted at once every 96 ms, the update interval of channel coefficients may become too long, resulting in the inferiority of the channel tracking ability. To avoid from the problem in T-DMBR, channel estimation has to be performed in data symbols as well as in the pilot symbol. During the reception of data symbols, decision-directed (DD) methods are usually adopted because of the absence of known pilot symbols [6]. Prior to performing DD channel estimation (CE), it is required that more precise and faster estimation should be carried out during the reception of the known pilot symbol of PRS. To achieve this goal, we propose a partitioned CE method in PRS of increasing the number of updates by partitioning transformed PRS in time domain.

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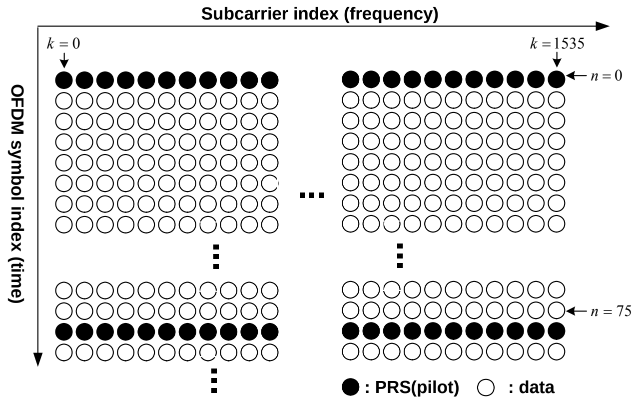

Fig 1. Arrangement of Phase Reference Symbols in the T-DMB system.

This paper is organized as follows. In section II, the T-DMB system is briefly overviewed. In section III, the basic principle and the conventional adaptive algorithm for feedback cancellation are presented. Then, the partitioning method is proposed to improve the feedback cancellation performance. Simulation result, in section IV, verifies the performance of the proposed method. Finally section V concludes this paper.

II. Overview of the T-DMB System

The T-DMB system is based on the European digital audio broadcasting (DAB) system known as Eureka-147 which has adopted coded orthogonal frequency division multiplexing (OFDM) and differential quadrature phase shift keying (DQPSK) [7]. As well as audio services in DAB, T-DMB has provided video services almost the same as terrestrial DTV contents with the enhanced bit error immunity supported by additional Reed-Solomon coding and convolutional interleaving of MPEG-4 encoded video data [8]. The pilot structure of the T-DMB system, which affects the performance of the feedback canceller, is shown in Fig. 1. In the T-DMB system, the Phase Reference Symbol (PRS) for DQPSK is the only pilot which can be used. As shown in Fig. 1, the PRS has the block-type arrangement and appears every 76 OFDM symbols. Here, if we adopt a feedback canceller which reduces the effect of the feedback channel, there is a problem in convergence speed because of the long pilot interval. Especially, in dynamic feedback channel, the problem can be serious.

III. Feedback Cancellers for T-DMB

A. *Basic principle of a Feedback Canceller*

Fig. 2 shows a T-DMB repeater with a feedback canceller. For notational convenience, let use frequency-domain notations for all signals. $X(\omega)$ denotes a transmitted signal from the host station and $N(\omega)$ is white Gaussian noise existing between the host station and the repeater**.** Next, let the frequency response of the feedback channel be $H_f(\omega)$ and the output signal or the re-transmitted signal of the repeater be $S(\omega)$. The received signal $R(\omega)$ then becomes the sum of

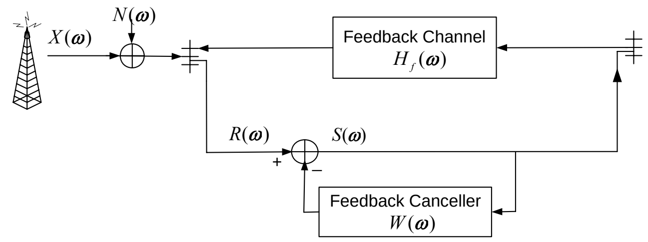

Fig. 2 A T-DMB Repeater with a feedback canceller.

$X(\omega)$, $N(\omega)$ and $S(\omega)\cdot H_f(\omega)$ since the transmitted signal returns through the feedback channel. The re-transmitted signal $S(\omega)$ and the receiver signal $R(\omega)$ can be described by

$$S(\omega) = R(\omega) - S(\omega)\cdot W(\omega) \tag{1}$$

and

$$R(\omega) = X(\omega) + N(\omega) + S(\omega)\cdot H_f(\omega), \tag{2}$$

respectively. By using (1) and (2), we can get the transfer function of the entire system of the T-DMBR, $F(\omega)$ as

$$F(\omega) = \frac{S(\omega)}{X(\omega)} = \frac{1}{1-\left(H_f(\omega)-W(\omega)\right)} + \frac{N(\omega)}{\left\{1-\left(H_f(\omega)-W(\omega)\right)\right\}\cdot X(\omega)}. \tag{4}$$

Inserting $E(\omega) = H_f(\omega) - W(\omega)$ in (4) and assuming that $N(\omega)$ is sufficiently smaller than $X(\omega)$ produces [4]

$$E(\omega) = 1 - \frac{1}{F(\omega)}\left(1+\frac{N(\omega)}{X(\omega)}\right) \cong 1 - \frac{1}{F(\omega)} = 1 - \frac{X(\omega)}{S(\omega)}. \tag{5}$$

The derived result of $E(\omega)$ in (5) is the estimation error of the feedback channel. The purpose of the feedback canceller is to reduce the effect of the feedback channel by minimizing the estimation error, *i.e.*, the value of $|E(\omega)|$ or $|E(\omega)|^2$.

B. *Adaptive Algorithm*

To minimize $|E(\omega)|^2$, we use the least-mean-square algorithm of minimizing the time-domain estimation error of $e(n,k)$ which is obtained by performing the inverse Fourier transform of $E(\omega)$. Here, n is the OFDM symbol index in time and k is the filter-coefficient index. To update the coefficients of the adaptive filter, $e(n,k)$ is multiplied by a rectangular window function $rect(k)$, and then the coefficients are sequentially updated by applying the following equation [5] of

$$w(n,k) = w(n-1,k) + \mu\cdot rect(k)\cdot e(n,k), \tag{6}$$

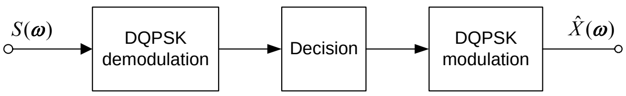

Fig. 3 Symbol decsion for DD estimation in data-symbol duration.

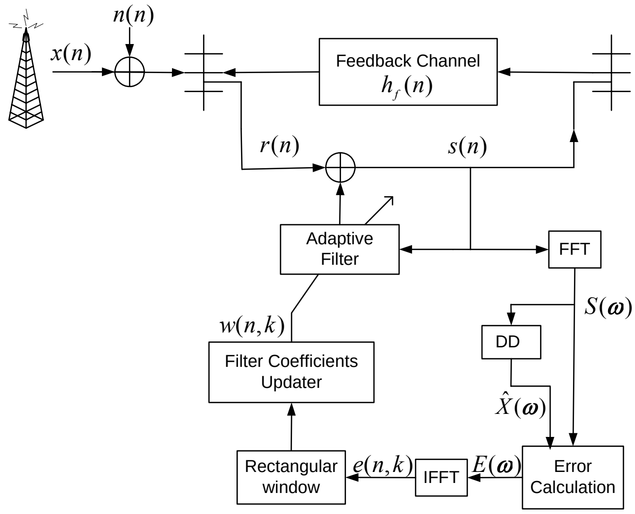

Fig. 4 Model of T-DMBR incorporating the demodulation-type feedback canceller based on DD channel estimation.

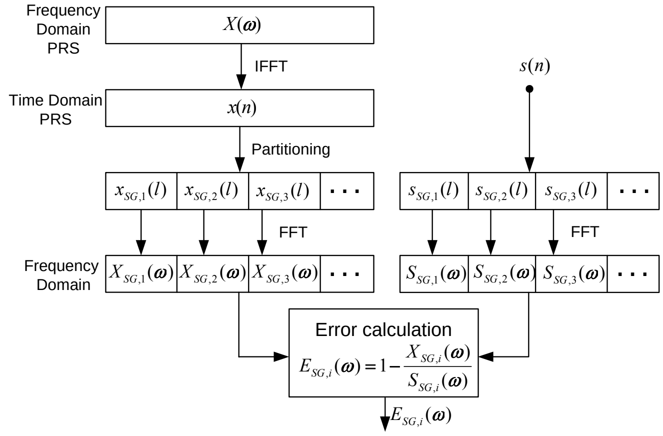

Fig. 5 Basic concept of partitioning of a transformed PRS in time domain.

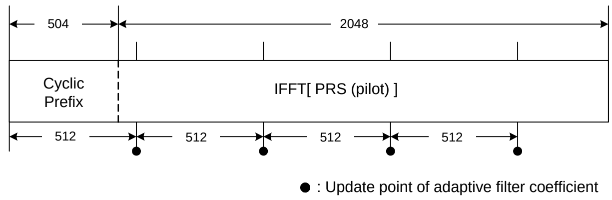

Fig 6. 512-point partitioning of PRS with a cyclic prefix.

where the step size μ is smaller than 1 and the rectangular window function is defined by

$$rect(k) = \begin{cases} 1 & (1 \le k \le M) \\ 0 & (\text{otherwise}) \end{cases}. \tag{7}$$

Here M is the total number of taps of the adaptive filter.

The update procedure of the adaptive algorithm is performed at the pilot symbol, because we must know the transmitted symbol $X(\omega)$ from the host station to calculate $E(\omega)$. However, in the T-DMB system, as mentioned in section II, the pilot symbol has the long period of 96 ms corresponding to 76 OFDM symbols, so we may not update the filter coefficients frequently enough to appropriately track channel variation. Therefore, the feedback canceller needs to update their coefficients even in data-symbol duration. Since there are no pilot symbols in data-symbol duration, DD methods are usually used for the compensation of the absence of known pilots [6]. Fig. 3 shows one of DD methods for finding the estimates of the transmitted symbols in the T-DMB system. Pursing the original objective of the canceller, the re-transmitted signal should approach to the transmitted signal of the host station. This means that the re-transmitted symbols, which are obtained by performing DQPSK demodulation of the re-transmitted signal, can be used for the estimates of the transmitted symbols. Consequently, we can obtain the feedback channel estimation error $E(\omega)$ by using the estimated signal $\hat{X}(\omega)$ as a pilot. The T-DMBR model incorporating the above-described feedback canceller based on DD channel estimation (DDCE) is illustrated Fig. 4.

C. *Partitioning of a Transformed PRS in Time Domain*

The performance of the feedback canceller based on DDCE highly depends on the estimation accuracy of data symbols. The estimation accuracy of DDCE can be higher as the initial condition of estimated coefficients becomes closer to the steady-state solution. The initial condition of DDCE is determined after the adaptation with known pilots in PRS duration and thus it is required to minimize the estimation error as small as possible during the PRS adaptation.

In the T-DMB system, there is only one iteration to update filter coefficients during one PRS. This update scheme does fail to meet the initial condition for DDCE to properly operate during the data symbols. To reach the required condition, we propose a partitioned CE method in PRS of increasing the number of updates by partitioning transformed PRS in time domain.

The basic concept of the partitioning method is shown in Fig. 5. The time-domain pilots which is the transformed PRS by the inverse fast Fourier transform (IFFT) can be partitioned into several subgroups, and the frequency spectrum of each subgroup is obtained by performing the fast Fourier transform (FFT). In Fig. 5, $X_{SG,i}(\omega)$ represents the frequency spectrum of each subgroup. Here. i is the partitioned subgroup index. The channel estimation error can be calculated by using $X_{SG,i}(\omega)$ and $S_{SG,i}(\omega)$ which is the frequency spectrum of the re-transmitted signal corresponding to $X_{SG,i}(\omega)$.

Note that the cyclic prefix used to make guard interval can be also utilized as the time-domain pilots. Fig. 6 shows an

TABLE I
T-DMB SYSTEM PARAMETERS

Parameters	Specifications
FFT size	2048
Number of transmitted carriers	1536
Guard interval	504
Sample time	1/2048000 seconds
Nominal bandwidth	1.536 MHz
Modulation scheme	π/4-DQPSK
Transmission scheme	COFDM

TABLE II
FEEDBACK CANCELLER PARAMETERS

Parameters	Specifications
Feedback gain	0 dB
Feedback delay time	0.5 μs (1 tap)
Additive noise in main channel : N(ω)	40 dB
Adaptive filter length	10 μs (21 taps)
Coefficient update step size : μ	0.1

example of time-domain partitioned groups including the cyclic prefix, each of which includes 512 time-domain pilots. Since the update is performed once per one subgroup, the number of iterations becomes four in this example, resulting in four updates with one PRS.

The partitioning method may provide a good solution that the adaptive filter goes to the desired initial condition for the proper operation of DDCE only if we find the appropriate size of time-domain subgroups which varies with the channel condition. The smaller size of a subgroup increases the number of updates but yields lower resolution in the frequency spectrum of the channel estimation error, vice versa. Therefore, the size of the subgroup should be properly determined by considering channel condition. When the condition is severe, the size should be enlarged. Otherwise, the size should be chosen to be reduced. As a result, we can increase the meaningful update number by using the well-established initial condition in DDCE via the partitioning method.

IV. SIMULATION RESULTS

We performed computer simulations to verify the performance of the proposed partitioned channel estimation method for feedback cancellation in the T-DMB Repeater. The system parameter of T-DMB is described in Table I [7] and feedback canceller parameters are given in Table II, Perfect synchronization was assumed to verify the performance of feedback cancellation with and without the proposed method. The measurement of the performance is defined by

$$P_{residual} = 10\log_{10}\left(\frac{|s(n)-x(n)|}{E\left[|x(n)|\right]}\right)^2. \tag{8}$$

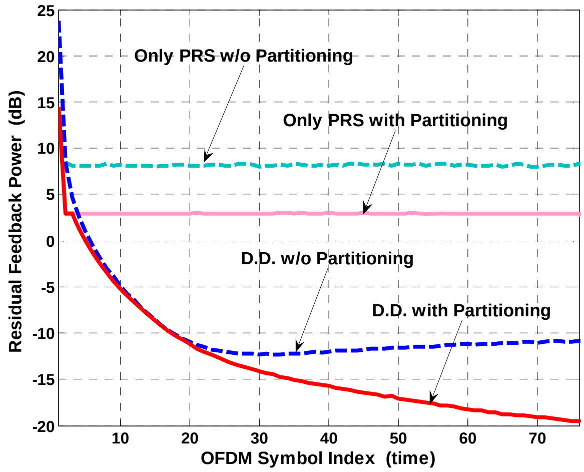

Fig. 7 The comparison of the feedback cancellers with and without proposed method

Here, $P_{residual}$, $x(n)$, and $s(n)$ denote residual feedback power (RFP), the transmitted signal from the host station, and the output of the feedback canceller, respectively.

The simulation result for the feedback canceller with and without the proposed partitioned channel estimation method in 76 OFDM symbols corresponding to one frame is shown in Fig. 7. The result shows that the performance of feedback cancellation based on DDCE is superior to that of the method which only uses PRS in terms of RFP due to the difference of channel estimation update interval. RFP is additionally reduced in all cases by applying the partitioned channel estimation method. This result means that the proposed method can increase the number of updates in PRS duration, resulting in lower RFP. Since the small RFP is closely related to the re-transmission power, the proposed method will improve the performance of T-DMBR.

V. CONCLUSIONS

In this paper, we proposed a partitioning method for feedback channel estimation in a T-DMB repeater. The partitioning method showed a good convergence performance in terms of residual feedback power. This result is based on the improvement of the accuracy of channel estimation by the proposed method which can increase of the number of updates in PRS duration. In the T-DMB repeater, the reduction of the effective feedback signal means the increase of the retransmission power. This is directly linked to the enlargement of the coverage, resulting in cost effectiveness. Therefore, it is expected that the T-DMB repeater with the proposed method could contribute the expansion of T-DMB service and establishment of the stable service environments.

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