TELEMETERING METHOD USING DELAYED FRAME TIME DIVERSITY (DFTD) AND REED-SOLOMON CODE

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ABSTRACT

This paper proposes a telemetering method consisting of delayed frame time diversity (DFTD) as the inner code and Reed-Solomon (RS) code as the outer code. DFTD is used to transmit a real-time frame together with a time-delayed frame which was saved in the memory during a defined period. The RS code is serially concatenated with DFTD. This method was applied to the design of telemetry units that have been used for over ten flight tests. The data results of the flight test for four cases with no applied code, with DFTD only, with the RS code only, and with both DFTD and the RS code are used to compare the number of error frames. The results also show that the proposed method is very useful and applicable to telemetry applications in a communication environment with a deep fade.

KEY WORDS

Delayed frame time diversity (DFTD), Reed-Solomon code, merging telemetry data

INTRODUCTION

Primarily due to its simplicity and robustness, PCM/FM(Pulse Code Modulation /Frequency Modulation), which has PCM frame format based on IRIG standard-106 Class I for RF links, has been used as the main modulation scheme for over 30 years [1]. Consequently, most telemetry facilities have invested significant capital in equipment specifically for use with PCM/FM.

One of the primary goals of telemetry engineering is to provide better received data for review and analysis, and there have been many approaches to reduce the number of erroneous frames in telemetry data as a result of flight tests.

One approach is to improve the performance of RF data links with the use of modern modulation techniques such as ARTM Tier I &II [2]. While these methods have helped to accomplish this goal, this approach is not easily applicable as it requires a significant investment of new equipments.

Another approach is to apply FEC (Forward Error Correction) such as Reed-Solomon (RS) codes, Turbo codes and low-density parity-check (LDPC) codes by which the additional information is used to recover the original data. In a communication environment with only AWGN (Additive White Gaussian Noise), to apply FEC is the obvious and inevitable solution to reduce the number of frame errors. However, these channel codes will have no effect if severe drops in the channel SNR (Signal to Noise Ratio) occur continuously over the order of msec due to reasons such as multipath fading, a vehicle shadowing the transmitting antenna, or nulls in the transmitting antenna pattern [3] as the multipath immunity capability of FEC is under the order of msec [4]. Therefore, a spatial diversity technique is used with the FEC approach in which telemetry data are merged from several receiving sites [5][6][7]. However, running multiple sites is not always possible as this requires significant manpower and high costs.

This paper introduces an approach, a type of time diversity technique, which is added to the implementation of the FEC technique, and shows that this new approach can significantly reduce the amount of errors in telemetry data.

INNER CODE AND OUTER CODE SCHEME

The proposed telemetering method consists of DFTD as the inner code and RS code as the outer code as shown Figure 1. DFTD defined in this paper is a variant of the PCM/FM inner code [2], which is used to transmit a PCM frame [8] and its time-delayed frame. The outer code is a serially concatenated RS coded block code and is implemented after additionally encoding image signal.

In addition FM (Frequency Modulation) is used for the RF link. The channel environment includes AWGN, multipath fading, a vehicle shadowing the transmitting antenna, the effect of the transmitting antenna null pattern, etc.

The RF strength recorder records the AGC output signal of the ground receiver. The output signal of the receiver video connector is sent to the RS decoder and stored in the data recorder through a bit synchronizer at the same time. The RS decoder performs outer decoding before separating the image signal. The processing system displays only real-time frames while saving both real time frames and delayed frames into a PCM file, which uses the filename extension of .pcm and assigns 16 bits to each word of PCM frame. Inner decoding is used to divide the PCM file into a PCM file consisting of only real-time frames and the other file consisting of only delayed frames as one of the telemetry post processing activities. The telemetry data for engineering analysis are finally attained by merging each separate PCM file on the same time basis.

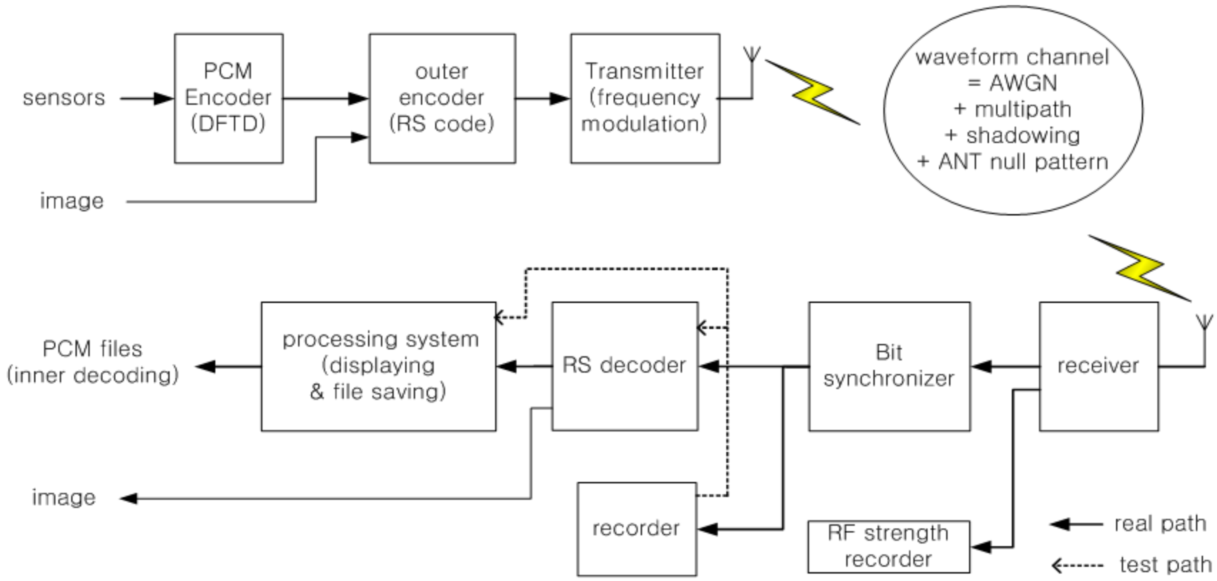

Figure 1: Block diagram of the overall scheme.

In Figure 1, the real path is the data flow for the flight test, and the test path is used for obtaining data to analyze this new scheme after the flight test. The onboard telemetry unit, RS decoder, and processing system are not commercial products, but are the prototypes that have been independently developed.

DFTD SCHEME

In a traditional PCM encoder, the output of the digital multiplexer, a real time frame, is converted from parallel data to a PCM stream. However, in the DFTD scheme, as shown in Figure 2, the time-delayed frame saved in the memory during the defined period(T [msec]) is converted into a PCM stream along with the orignal real-time frame. Its frame structure is shown in Figure 3.

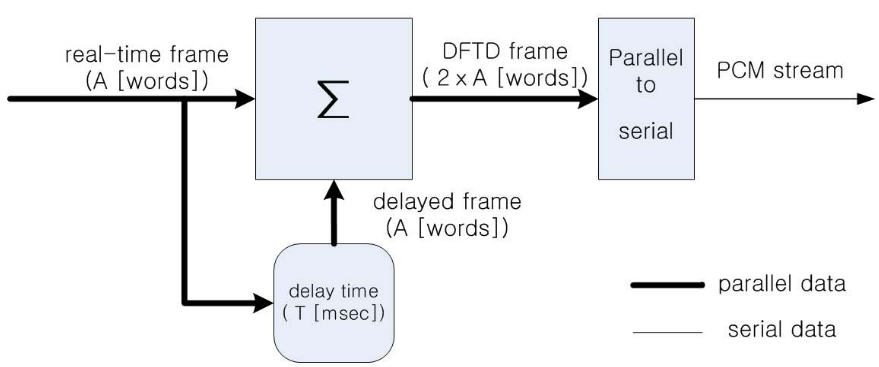

Figure 2: Implementation of DFTD.

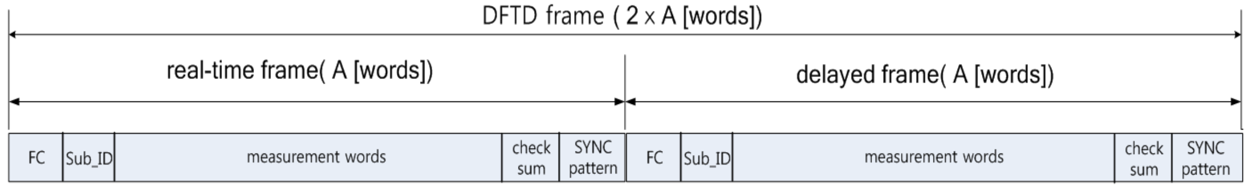

Figure 3: DFTD frame structure.

A real time frame and delayed frame exist internally with the same configuration and size. If one frame consists of the number of A words, a delayed frame has the same number of words. Therefore, a DFTD frame has 2-times the number of A words. However, only the internal frames have different values of the FC (Frame Counter) and Sub_ID (Sub_frame identification).

In the case of a real-time frame, the FC has the present time and Sub_ID always has the value '1'. In the other case, the FC has the past time and Sub_ID always has the value '2'.
FC, Sub_ID, checksum, and SYNC (Synchronization code) pattern are used as references in order to divide a file of DFTD frames into a file of real-time frames and file of delayed frames during post-processing as inner decoding. Only if all of these four words have a reasonable value, each frame is accepted; otherwise, they are discarded (substituted with zero frames in which the measurement words all have zeros). The FC is incremented by one every frame and regarded as time included in the telemetry data only if multiplying the frame period time. A 30bit word is allocated, giving the FC enough bits to count the frames during the whole test period without recycling. Sub_ID is intended to distinguish between a real-time frame and delayed frame. A checksum word is appended to each frame as an extra word to check the integrity of each frame using a so-called longitudinal parity check algorithm. The SYNC pattern is one of the recommended frame synchronization patterns of IRIG 106 [8].

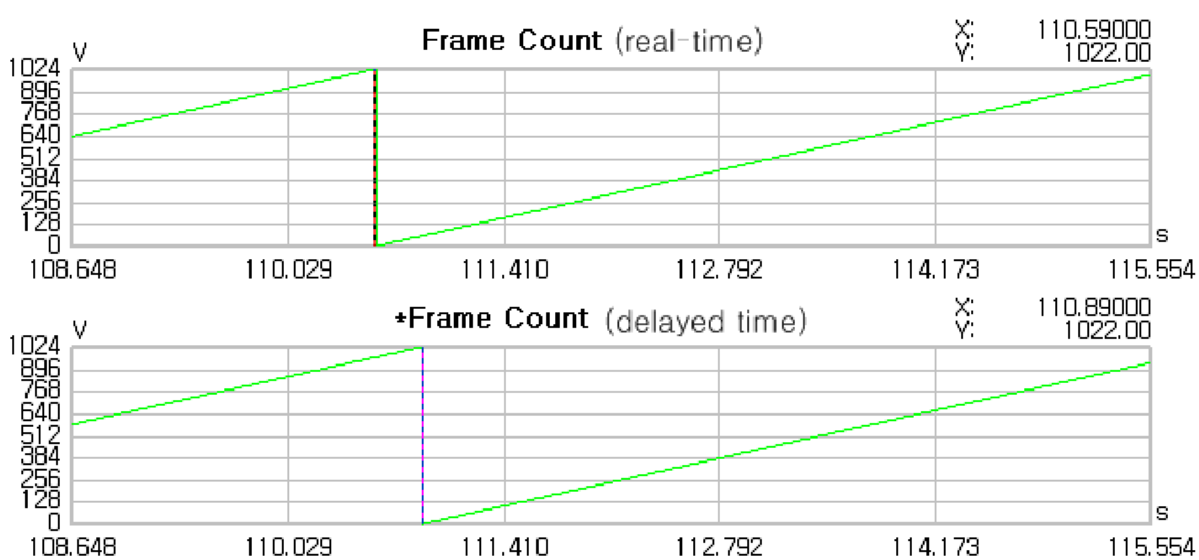

Figure 4: DFTD verification.

Figure4 shows that the FC value of real time data is ahead of the value of delayed data by the defined amount of delay time to verify the proper implementation of the telemetry unit with DFTD.

Noise power is increased by 0.8 [dB] because the overall bandwidth including the image data is increased 1.2 times by implementing DFTD.

SERIALLY CONCATENATED RS CODE

The application of even more effective FEC coding is possible, but will result in only a small improvement. Therefore, the RS (n, k) = (255,239) code operating on 8-bit symbols has been selected as the outer code [9]. This code has k = 239 data symbols plus 16 parity symbols in an n = 255 symbol block, and is capable of correcting up to 8 symbol errors per block.

Verification of the telemetry unit (TLM) with RS code is performed, as shown Figure 5. In this test configuration, inserting an attenuator between the telemetry unit and ground test unit and connecting each with a cable, the PCM data file does not include errors unless noises are added into the system. A pin of the RS decoder is additionally assigned for error insertion, and a square wave signal with an amplitude of 3V and offset of 1.5V is applied to the pin using a function generator. Considering the error correcting capacity, occurrence of SYNC errors in the data is checked while increasing the frequency of the wave signal.

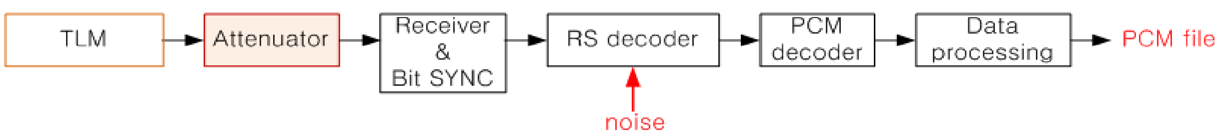

Figure 5: RS code verification.

In the test results, no errors are found up to the frequency corresponding to the 8 symbol errors. Also, the time of 85 [usec], as the reciprocal of this frequency, implies the multipath immunity capability of the designed RS code, in which 8 symbol errors can be corrected.

PERFORMANCE RESULTS USING FLIGHT TEST DATA

We compare the number of error frames for four cases with no applied codes, with DFTD only, with RS code only, and with both DFTD and RS code.

First, an RS decoded data file named 'RS' and a bypassed data file named 'noRS' are obtained as the recorder replays the saved data following the test path of the Figure 1. Next, these two data files are divided into real time frame data files and delayed frame data files, and therefore there are four files, a real-time data file without RS decoding named 'noRS1', time-delayed data file without RS decoding named 'noRS2', real-time data file with RS decoding named 'RS1', and time-delayed data file with RS decoding named 'RS2'. The two data files without RS decoding, 'noRS1' and 'noRS2' are merged into a file named 'noRS&DFTD', and the other two data files with RS decoding, 'RS1' and 'RS2' are merged into a file named 'RS&DFTD'.

The preparation steps obtaining telemetry data for analysis have been conducted until now by dividing and merging PCM files on the same time basis. In the process of this post-processing, a 'frame optimizer' program [10][11] is used.

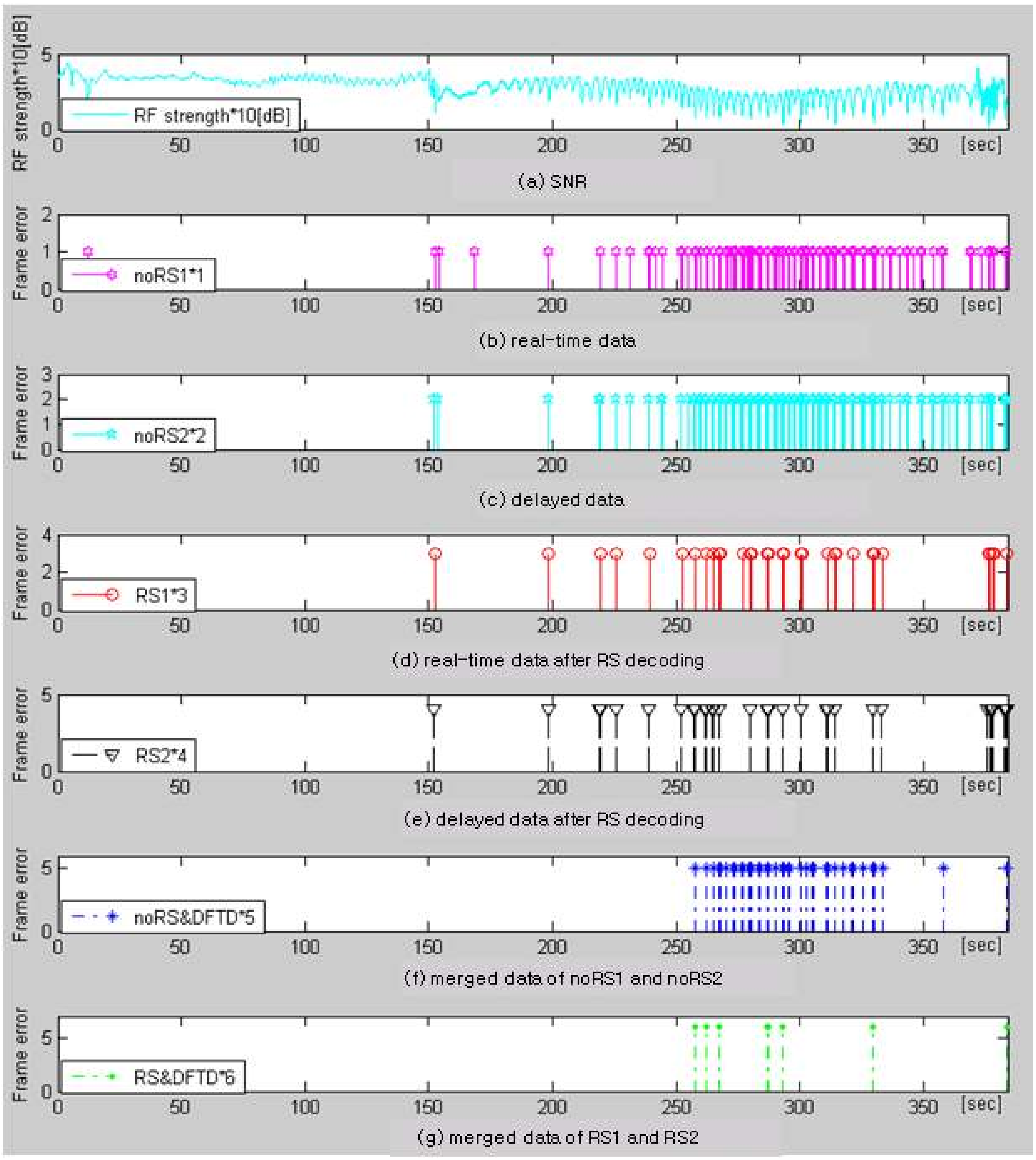

Figure 6: A comparison of the numbers of error frames.

Figure 6(a) shows the SNR (Signal to Noise Ratio) measured from the receiver output during the flight test. The figure shows that a real communication environment has a strong destructive interference, referred to as a deep fade, which may result in a temporary failure of communication due to a severe drop in the channel SNR. Figure 6(b) shows the frame errors in the case of 'noRS1' to which both DFTD and RS-code are not applied, where frame errors indicate that there are invalid values in specific words such as sub_ID, FC, SYNC pattern, and checksum. Figure 6(c) shows the frame errors in the case of 'noRS2', which has the similar amount of errors and is delayed by the delay time in comparison with Figure 6(b). Figures 6(d) and (e) show the frame errors in the case of 'RS1' and 'RS2', respectively, to which only an RS code is applied, and which have 36% of the errors shown in Figure 6(b). Figure 6(f) shows the frame errors in the case of 'noRS&DFTD', to which only DFTD is applied by merging the data in Figures (b) and (c), and which has 23.3 % of the errors shown in Figure 6(b). Figure 6(g) shows the frame errors in the case of 'RS&DFTD', to which both DFTD and RS-code are applied by merging the data in Figures (d) and (e), and which has 3 % of errors shown in Figure 6(b). The comprehensive results of several cases are shown in Figure 7 in the form of a Venn diagram and are shown in Table 1.

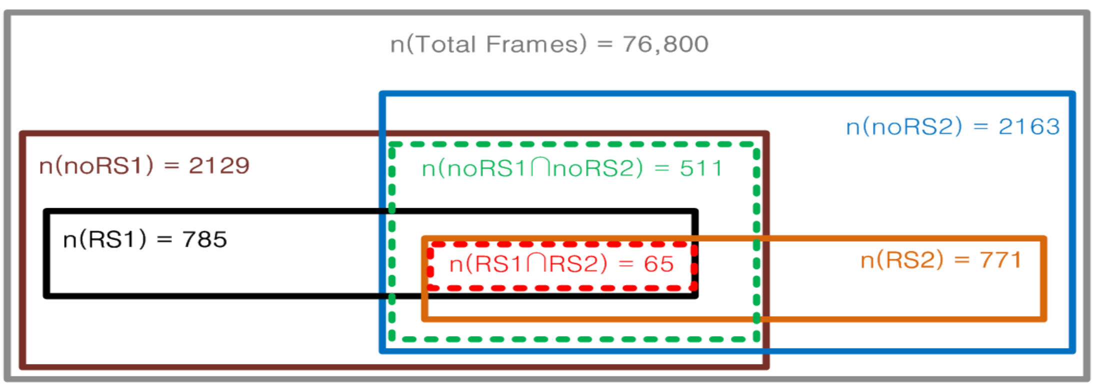

Figure 7: Venn diagram of the error frames.

Table 1: Frame error table (* the number of total frames : 76,800 [ea]).

PCM data	error # [ea]	error rate [%]	normalization to noRS1 [%]	case
noRS1	2192	2.8542	100	no applied code
noRS2	2163	2.8164	98.7	
RS1	785	1.0221	35.8	the RS code only
RS2	771	1.0039	35.2	
DFTD only	511	0.6654	23.3	DFTD only
RS & DFTD	65	0.0846	3.0	both DFTD and the RS code

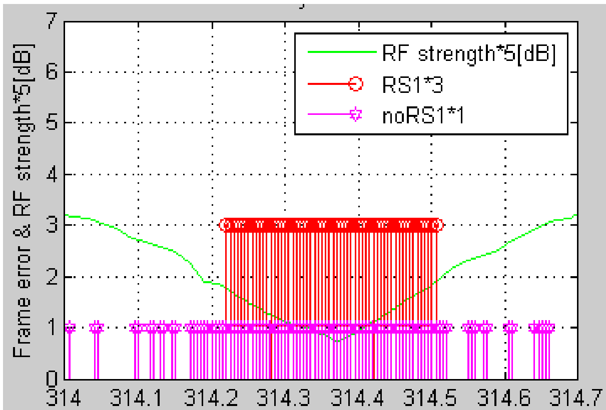

Figure 8: RS code performance.

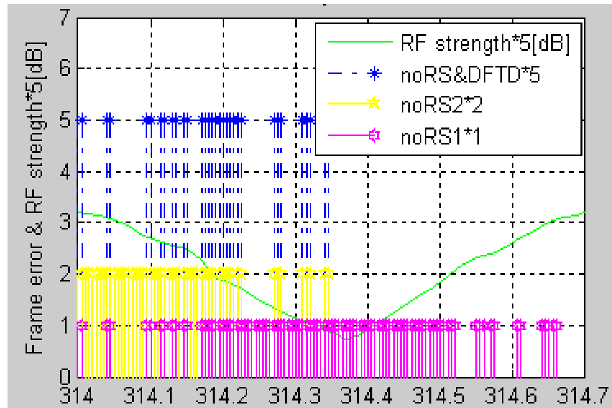

Figure 9: DFTD performance.

Figure 8 to Figure 10 have the same time period but represent different performances.

When comparing 'noRS1' with 'RS1', applying only the RS code has a good effect if the SNR is greater than 12 [dB], but has no effect if SNR drops below 12 [dB], as shown in Figure 8. When comparing 'noRS1' and 'noRS2' with 'noRS1&DFTD', applying only DFTD has a good effect if a real time frame and delay frame have errors at different times, but no effect if the errors of these frames occur at the same time, as shown in Figure 9.

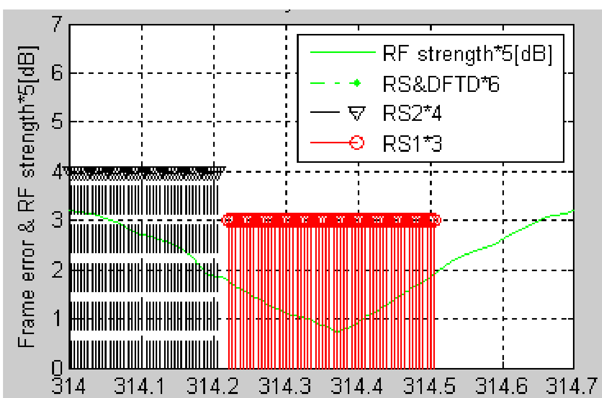

Figure 10: RS code & DFTS performance.

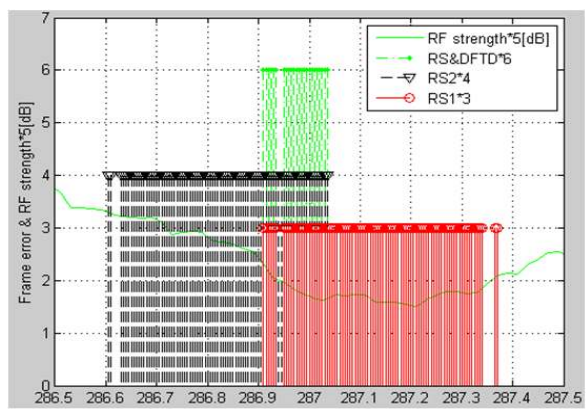

Figure 11: remaining errors

When comparing 'RS1' and 'RS2' with 'RS&DFTD', which represents the performance of the method proposed in this paper, applying both DFTD and RS-code has a much better effect than the other cases because the errors outside of the fading period are primarily removed by RS code, and the errors in the fading period are secondarily removed by DFTD, as shown in Figure 10. Some errors may still remain, as shown in Figure11, while a deep fade lasts longer than the designated delay time of DFTD. However, these errors will obviously be removed only if the delay time is reassigned with 4/3 times the value of the above case. In addition, it is no wonder that a combination of the proposed method and space diversity with several receiving sites is more effective [10].

CONCLUSIONS

A new telemetering method was introduced and its performance evaluated by analyzing the acquired data from a flight test. An RS code is effective in removing the errors affected by an AWGN channel, while DFTD is effective on deep fading errors that might occur by a multipath, shadowing, or transmitting antenna pattern, and which last relatively longer than AWGN channel errors.

The scheme of the proposed method has DFTD as the inner code and RS code as the outer code, and the effectiveness of these codes appears independent of each other. Therefore, the new scheme makes it possible to remove almost all errors for AWGN and deep fading environments, as shown in the analysis results in this paper.

This new proposed method is one possible approach to meet the goal of telemetering engineers in gaining errorless data, although the quality of real-time monitoring can be degraded slightly due to the increased bandwidth from implementing DFTD, and its efficiency can be accomplished only through post-processing.

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