Implementation and Field Test of a New Channel Estimation Technique for DVB-T System

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Abstract

The European standard for digital terrestrial transmission, DVB-T, has been designed for fixed, portable and mobile reception. This versatility is due in part to Coded Orthogonal Frequency Division Multiplexing (COFDM). OFDM can provide large data rates with sufficient robustness to radio channel impairments. During the deployment of terrestrial DTV broadcasting systems, very often the channel characteristics have to be captured for the DTV coverage study, reception problem diagnosis and service planning. The software implementation of a new channel characterization technique using frequency domain pilot time domain correlation (FPTC) method for DVB-T systems is presented in this paper. This technique exploits the pilot sequence embedded in the DVB-T signal, which is derived from the frequency domain pilots and known to the receiver. The major advantages of this proposal, compared to other DTV channel characterization techniques, are its wide amplitude dynamic range, robustness to frequency synchronization errors, and avoidance of interruptions to the broadcasting service.

Index Terms Channel estimation, OFDM, DVB-T

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has been used in the DVB-T standard, in which a large number of orthogonal, overlapping, narrowband subchannels, or subcarriers, are transmitted in parallel over the available bandwidth [1][2]. The channel characterization of DVB-T system is often done in the frequency domain [3][4]. However, the channel information can only be reliable if the DTV receiver can successfully achieve reliable frequency and time synchronizations. Unfortunately, this is difficult under severe multipath conditions and strong co-channel and adjacent channel interferences. Another way for the channel estimation is to send a training sequence occupying the same spectrum, but the regular broadcasting service has to be interrupted. These observations motivates the study of new in-service DTV channel characterization methods.

A simple channel characterization technique using the frequency domain pilot time domain correlation (FPTC) method for DVB-T has been proposed by X. Wang et al. [5]. This new technique is based on the time domain correlation between the received signal and the time domain pilot sequence embedded in the OFDM signal, which is derived from the frequency domain pilots and known to the channel estimation device. It is shown that the time domain correlation function of the received signal and the pilot sequence can be approximated as the convolution between the channel impulse response and the time domain autocorrelation function of the pilot sequence. Channel impulse response can then be obtained.

II. DVB-T REFERENCE SIGNALS OVERVIEW

In the DVB-T standard, the symbols in an OFDM frame contain data and reference information. Since the OFDM signal comprises many separately-modulated carriers, each symbol can in turn be considered to be divided into cells, each corresponding to the modulation carried on one carrier during one symbol. An OFDM frame contains the following reference signals: scattered pilot cells, continual pilot cells, and Transmission Parameter Signalling (TPS) carriers. The pilots can be used for synchronization and channel estimation. The value of the scattered or continual pilot information is derived from a PRBS (Pseudo Random Binary Sequence), one for each of the transmitted carriers. Reference information is transmitted in scattered pilot cells in every symbol. Scattered pilot cells are always transmitted at a “boosted” power level. In addition to the scattered pilots described above, 177 continual pilots in the DVB-T 8K mode are inserted according to a certain pattern. Here “continual” means that they occur on all symbols: a detailed list of carrier indices for continual pilot carriers is given in [6]. The continual pilots are all modulated according to the reference sequence and are also transmitted at the “boosted” power level.

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III. FTPC IMPLEMENTATION PROGRAM

A. FPTC algorithm

The principle of the proposed time domain channel estimation method is shown in Figure 1. At the transmitter, the complex data in the frequency domain can be divided into two different sets, the data symbol to be transmitted and the pilot symbols for channel synchronization and estimation. Therefore, the DVB symbol \( s(t) \) consists of two parts, \( s_d(t) \) and \( s_p(t) \), which are transformed from data set and pilot set, respectively. At the receiver, the received signal is passed through a correlator matched to the reference signal \( s_p(t) \), and the output of the correlator is the estimated channel response. In [5], the correlator output is given by

\[
R_{rp}(n) \approx h(n) \sigma^2_p + w_1(n)
\]

where \( w_1(n) \) is the noise and interference and \( \sigma^2_p \) is the variance of the reference signal \( s_p(t) \). The cross-correlation function of the reference signal, \( R_{rp}(n) \) can be used to estimate the channel impulse response \( h(n) \). A detailed mathematical description of the FPTC channel estimation method is presented in [5].

![Fig. 1. Principle of the proposed FPTC technique [5].](image)

B. Channel estimation program

The data analysis (channel estimation) program block chain is illustrated in Figure 2. The measurements provide digital recordings of DVB-T 8K mode signals. According to the standard, 1/12 of the OFDM subcarriers are used for pilots, which could be exploited for synchronization and channel estimation.

The data analysis program performs the following tasks:

1) For a newly recorded file, the program must scan through the first data segment of one DVB symbol, in order to locate the starting point of the first symbol. Since the DVB signal has a cyclic prefix, this is used for the synchronization of the system [1]. Once the synchronization is done, one DVB symbol will be used for further processing after discarding the guard interval.

2) The channel estimation is based on the correlation between the received signal and the reference signal in baseband. The received signal has to be down converted to baseband. An algorithm is developed to locate the accurate IF frequency of the received signal for downshifting.

3) The scattered pilots have four possible patterns [6]. These four patterns are used to correlate the received signal. Only one correlation output should have a high peak-to-average value, and thus used for channel estimation.

4) The correlation based on scattered pilots has a period of 1/12 OFDM symbol length, and consequently it can be used for channel estimation with multipath delays up to 1/12 of the symbol length. For the case of long multipath delay spreads, continual pilots can be used alternatively.

IV. LABORATORY EXPERIMENTS

Figure 3 shows the block diagram of a laboratory DTV channel recording set-up designed by the Television Broadcast Technologies Research group at the Communication Research Centre Canada (CRC). The measurement was carried out in a laboratory where a LOS path between the transmitter and receiver was present. The system consists essentially of a VHF-UHF tuner, a digitizer board and a personal computer (PC) for data acquisition and processing.

The parameters of the DVB signal can be set in the DTV signal generator, e.g. the guard interval length, the modulation method, the coding rate, etc. Also, multipath components can be artificially introduced by the DTV signal generator for laboratory experiments. The DTV signal is
transmitted at RF frequency from the DTV signal generator, and received using transmit and receive antennas. At the tuner, the received signal is down converted from RF frequency to IF frequency of about 7.14 MHz. This IF frequency is not absolutely accurate, due to the precision of the crystal oscillator-mixer in the tuner. Since the frequency offset of the baseband signal has great effects on the channel estimation accuracy, some effort is made to examine the IF frequency accurately.

The output signal is recorded using a Compuscope CS14100 digitization board with a resolution of 14 bits per sample. The sampling rate was set at 25 Msamples/s which is not an exact multiple of the DVB symbol rate. Interpolation is used to resample the data.

During the measurement, we examine a series of laboratory recording in different conditions. First, a clean channel (ideal channel without multipath) is used to study the channel estimation algorithm. Then, several paths are inserted in the received signal. The processing for the above two cases is based on the embedded scattered pilots. Finally, the continual pilots are used to handle the long multipath delay cases.

A. Clean (no multipath) channel estimation from scattered pilots (laboratory environment)

Here, we analyzed the received signal from a clean channel in a laboratory measurement. Figure 4 (left) shows the synchronization output of the received signal. It is the autocorrelation result of the \( \Delta \) guard interval part of the signal with a part that is \( T_u \) seconds delayed. We find the offset with the autocorrelation peak value in the length of one symbol, and synchronization of the signal is thus obtained. We may use this figure to test if the received signal is a valid DVB-T signal.

Figure 4 (right) also shows the spectrum of the received IF signal. The observed noise level is about 30 dB below the signal level. The figure also shows the lower edge of the signal’s spectrum for down converting the IF signal. To achieve a higher frequency accuracy, a 16 times oversampling (8192 \( \times \) 16) is used for the IFFT operation.

The cross-correlation output of one DVB symbol with the scattered pilots is shown in Figure 5 (left) for the ideal (no multipath) channel. There is a main cross-correlation peak in the middle, and 12 secondary peaks on either side. The 12 secondary peaks are caused by the 1/12 pilot insertion of the scattered pilots. For the main correlation peak, a dynamic range of more than 30 dB can be achieved. By zooming near the main peak in this figure to about 1/12 of the FFT period, and changing the logarithmic scale into a linear scale, one obtains the estimated channel impulse response shown at the right of Figure 5.

B. Multipath channel estimation from scattered pilots (laboratory environment)

In this experiment, two significant multipath components, -5 dB and -2 dB relative to the strongest path, were introduced in the channel. The corresponding multipath (excess) delays were -1 \( \mu s \) and 2 \( \mu s \) respectively. The symbol correlation results and estimated channel impulse response are shown in Figure 6. It is observed, from Figure 6, that the delay time of the multipath components match exactly with the original value. The first multipath component is about 0.525 (-5.6 dB) and the second is about 0.8 (-1.9 dB), relative to the strongest path. The estimation error of the multipath amplitude is caused by the downsampling of the received signal, and could be reduced by upsampling the scattered pilot instead, with the tradeoff of a significant increase in the processing time.
C. Multipath channel estimation from continual pilots (laboratory environment)

The previous examples are based on the scattered pilot. For the case of a long delayed echo, we need to use the continual pilots instead. Figure 7 shows the correlation output using continual pilot. We note that instead of 12 peaks in the previous cases, we only have two correlation peaks at either side. However, the dynamic range drops significantly to about 10 dB: the noise level in the channel impulse response is significantly higher.

Fig. 6. Cross correlation between one DVB symbol and scattered pilot symbols (left) and estimated DVB channel impulse response (right).

Fig. 7. Cross correlation between one DVB symbol and continual pilot symbols (left) and estimated DVB channel impulse response (right).

V. FIELD EXPERIMENTS

The channel estimation algorithm was also implemented to process real-time received DVB-T signals. The receiver was set up in Amsterdam to capture the off-air DVB-T signal, and provide a channel estimation. There are four SFN transmitters in operation in the Amsterdam area and the terrain is very flat. The measurements were conducted in a mostly 5 story building residential area.

Figure 8 shows four estimated channel impulse responses collected for channel 21 (470-478 MHz, 1/4 guard interval, 8K mode) during the field measurements. The weather was bad, strong wind with periodic showers, so that the impulse response varies significantly over time. The time interval between two impulse responses measurements was about three minutes. As can be seen in this figure, the number of significant multipaths corresponds to the number of SFN transmitters.

Fig. 8. Estimated DVB channel impulse response (channel 21 (470-478 MHz), Amsterdam, September 11, 2003).

The 4th floor hotel room had relatively good access to all DTV transmitters, given the fact that most of the Amsterdam buildings are 5 stories high. The multipath distortion observed was quite strong. However, at lower heights, the SFN multipath distortion would be reduced due to non-line-of-sight propagation path, which greatly attenuate the multipath signal strength.

VI. CONCLUSION

The principle of a channel characterization technique using frequency domain pilot time-domain correlation (FPTC) is briefly discussed in this paper. This technique was implemented in software and used to analyze field measured data. The positive results of this test validated this new FPTC technique and confirmed that this method could be easily implemented in practice.

REFERENCES