Channel Estimation and Equalization of DVB-T in Fast Fading Multipath Channels

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***Abstract*—Early Terrestrial Digital Video Broadcasting Systems (DVB-T) were planned to work in Line-of-Sight (LOS) environments where a significantly high Signal to Noise Ratio (SNR) is guaranteed for all times. However, the recent DVB standards are sought to work in non-LOS conditions where the SNR is relatively low. Hence, in such environments, there is a need for a successful channel estimation and detection technique to take care of the fast channel fluctuations. This article is dealing with LS channel estimation and detection method for DVB-T signals over various multipath fading channel. The proposed method has been proven successful for up to 16 Quadrature Amplitude Modulation (QAM) constellations even when there is no LOS. However, the performance is found to be insufficient for an acceptable user experience for higher number of constellations.**

***Index Terms*—DVB-T, OFDM, multipath fading channel, LS estimation**

I. Introduction

As The Digital Video Broadcasting (DVB) standards develop the importance of Orthogonal Frequency Division Multiplexing (OFDM) shine brighter, especially when we consider the usage of smart phones as receivers. Due to its high data rate transmission capability with high bandwidth efficiency and robustness to multipath delay, OFDM is being used as a standard scheme in Digital Video Broadcasting-Terrestrial (DVB-T) [1]. DVB-T allows the usage of radio frequency spectrum efficiently, resulting in better sound and picture quality, possibility of adding new services, possibility of high definition pictures.

Communications of wireless devises in terrestrial environments rely on multiple copies of the transmitted signals arriving at the receiver through multiple paths. These paths with different arrival times and phases can add constructively to yield a healthy signal or destructively, to yield a faded signal. The situation gets worse when the channel becomes frequency selective and causes Inter Symbol Interference (ISI) [2].

DVB-T is more sensitive to channel fluctuations than single carrier schemes such as Frequency Division Multiple Access (FDMA) due to the hierarchical modulation techniques (such as 64-QAM quadrature amplitude modulation) employed [3], [4]. Early DVB systems were therefore designed to operate solely in Line-of-Sight (LOS) scenarios employing a high tower transmitter and roof-top receiver antenna [5]. However, losing the LOS between transmitter and receiver, the resulting signal at the receiver will consist of echoes only and makes a significantly los Signal-to-Noise-Ratio (SNR). In the case of No-LOS, for the system to operate successfully, the channel has to be sensed precisely using a reliable estimation method such as Zero Forcing (ZF) or Minimum Mean Squared Error (MMSE). The channel sensing is relatively easier when the channel is Non-Frequency-Selective (NFS) but becomes a trivial problem when the channel becomes Frequency Selective (FS) [3]. Cyclostationarity detector has made an achievement to sense the channel until -14dB SNR [6]. These detectors utilized multiple cyclic frequencies of OFDM signals used in DVB-T [6].

In general, the channel can be estimated by using a preamble or pilot symbols known to both transmitter and receiver. Choice of the best estimation method for a particular system depends on the aimed performance, tolerable computational complexity and speed of variation of the channel [7]. The block-type pilot is suitable for slow fading channel by estimating the channel along the time axis whereas the comb-type pilot would be chosen for equalizing fast fading channels [7], [8]. Arrangement of comb-type pilots suits well to the Least Square (LS), Minimum Mean Square Error (MMSE) and Least Mean Square (LMS) methods. However, the MMSE has been shown to perform much better than LS but at the cost of higher computational complexity in time-varying frequency-selective channels [3], [**7**], [8].

In this article the performance of DVB-T system with 4, 16 and 64-QAM modulations in 2k mode OFDM has been evaluated for the signals transmitted over the AWGN, Rician (LOS-case) and Rayleigh (Non-LOS case) channels. Comparing the performances revealed that the LS channel estimation method resulted in an acceptable performance for 4 and 16-QAM techniques but unacceptable performance for the 64-QAM.

The article is organised as follows: Section II reviews the DVB-T system in general and Section III concentrates on the channel estimation and detection techniques. Then in Section IV brief representation of channel models has been provided. Section V and VI covers the simulation results and conclusions respectively.

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II. Review of DVB-T Systesm

The functional block diagram of DVB-T system has shown in Fig. 1 as it is in [4]. Simply after getting signal from MPEG-2 transport multiplexer, six different changes will come into data before sending it throw OFDM system. They are known as transport multiplex adaptation and randomization for energy dispersal, outer coding (i.e. Reed-Solomon code), outer interleaving (i.e. convolutional interleaving), inner coding (i.e. punctured convolutional code), inner interleaving (either native or in-depth), mapping and modulation [4], [9].

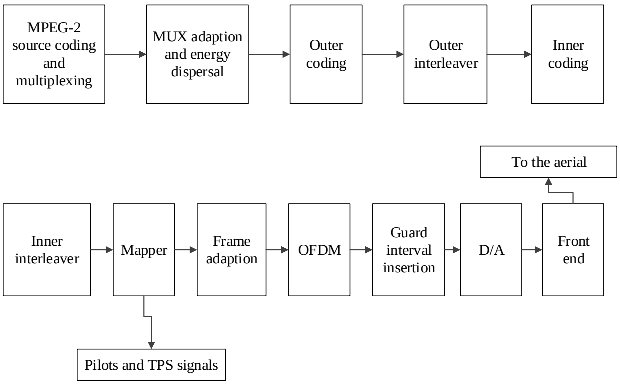


Figure 1. Terrestrial channel adapter [4]

MPEG-2 transport multiplex (MUX) packet consist of 188 byte, each includes 1 sync-word byte. After getting the MPEG-2 stream the aim is to achieve a flat power density spectrum and avoid accordance of long strings zeros and ones. Randomizing the data in this section in accordance with scrambler structure as it is in [4], adequate binary transitions will be ensured. In outer coding, by use of Reed Solomon code each 188- byte data added 16-byte redundancy to form of 204-byte transmission stream. By outer interleaving with depth I = 12, packets will be error protected [5]-[7]. In DVB system, choose of the most proper level of error correction for the data rate in either non-hierarchical or hierarchical transmission mode is critical. In inner coding block this will approach by punctured convolutional codes. Mother code has been set to ½ in polynomials generator so that encoder takes one-bit symbols as inputs and generates 2-bit symbols as outputs. By using the mother code, generating the different punctured convolutional code (such as 2/3, 3/4, 5/6 and 7/8) has made the system flexible in different purpose [4], [10]. Inner coding is used to lower the redundancy of the mother code.

Inner interleaving which includes bit-wise inter-leaver and symbol inter-leaver, has modified to avoid burst ISI and reduce the error rate. In this section OFDM modulation take a part and the choosing of the inter-leaver for both part depend on mode of OFDM. Bit-wise inter-leaver demultiplexed into v sub-streams, where v = 2 for QPSK, v = 4 for 16-QAM, and v = 6 for 64-QAM.

The demultiplexing is defined as a mapping of the input bits, onto the output bits [4]. Bit inter-leaver has the size of 126 bits but each case may have different sequence, thus in 2k mode each process repeated twelve times and in 8k mode 48 times per symbol. Symbol inter-leaver has planned to map v bit words onto 1512(in 2k mode) and 6048 (in 8k mode), carriers per OFDM symbol and the output is used for signal constellation in next block. To complete the process, constellations and the details of the Gary mapping will be applied to the OFDM modulation either it is QPSK, 16-QAM or 64-QAM. Frame will be formed by inserting pilots and Transmission Parameter Signalling (TPS) in this block. Parameter α define the exact proportion of constellation. The α is minimum distance between two constellation that carrying different values, divided by minimum distance of any constellation [4], [10]. In DVB-T nearly 10% of total subcarriers are transmitted by 2.5dB power which is higher than rest, this subcarriers are repeated each four OFDM symbols duration [6].

The core of DVB-T system lied on OFDM which by its own advantages make the system tuneable into 2 sub-carriers known as 2k and 8k mode, and 3 different modulations which are 64-QAM, 16-QAM and QPSK. DVB-T also has specified for two level hierarchical modulations and coding. In this case mapper and modulator map two independent MPEG transport streams, onto the signal constellation. The streams are known as high-priority and low-priority [4], [11]. In non-hierarchical mode, the single input stream is demultiplexed into v sub-streams. As the article focuses on the non-hierarchical 2k mode Table I provide the parameters for this mode as it is in [4].

TABLE I. Non-Hierarchical DVB-T in 2k Mode Parameters for 8MHz Channel [4]

Parameters	2K Mode
Elementary Period (T)	7/64 μs
Number of Carriers (K)	1705
Value of carrier number K_{min}	0
Value of carrier number K_{max}	1704
Duration (T_U)	224 μs
Carrier Spacing ($1/T_U$)	4464 Hz
Spacing between carriers K_{min} and K_{max}	7.61 MHz
Allowed Guard Interval Δ/T_U	1/4, 1/8, 1/16, 1/32
Duration of Symbol part T_U	224 μs
Duration of guard interval Δ	56 μs, 28 μs, 14 μs, 7 μs
Symbol Duration	280 μs, 252 μs, 238 μs, 231 μs
µs = Microsecond, Hz = Hertz, MHz = Megahertz	

III. Channel Estimation and Detection Technique

Between observed data and its expected value there is always some differences, minimizing squared of this discrepancies give the chance of estimating the parameters, which is called least square (LS) estimation method [**7**], [12].

We use this linear estimation method where we assume that there is no ISI and the OFDM use cyclic prefix to discard at the receiver to cancel out ISI [7], [13]. Lower complexity of LS and needless statistical information about channel and noise [14], let us to use it as an ideal estimation method in this research.

As the subcarriers in OFDM are orthogonal, pilot tones as $X_{[k]}$ can be representing for N subcarriers as it is in (1), and X is training symbol for N subcarriers [7]:

$$X = \begin{bmatrix} X_{[0]} & 0 & \dots & 0 \\ 0 & X_{[1]} & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \dots & 0 & X_{[N-1]} \end{bmatrix} \quad (1)$$

Noise and channel gain will affect the pilot symbols, equation (2) represents the received training signal as $Y_{[k]}$ where Z is the noise vector:

$$Y \triangleq \begin{bmatrix} Y_{[0]} \\ Y_{[1]} \\ \vdots \\ Y_{[N-1]} \end{bmatrix} = \begin{bmatrix} X_{[0]} & 0 & \dots & 0 \\ 0 & X_{[1]} & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \dots & 0 & X_{[N-1]} \end{bmatrix} \begin{bmatrix} H_{[0]} \\ H_{[1]} \\ \vdots \\ H_{[N-1]} \end{bmatrix} + \begin{bmatrix} Z_{[0]} \\ Z_{[1]} \\ \vdots \\ Z_{[N-1]} \end{bmatrix} = XH + Z \quad (2)$$

Assume that $\widehat{H}$ is the value of estimated channel, minimizing the (3) and (4) gives the solution to LS channel estimation.

$$J(\widehat{H}) = \left\|Y - X\widehat{H}\right\|^2 = \left(Y - X\widehat{H}\right)^H\left(Y - X\widehat{H}\right) = Y^H Y - Y^H X\widehat{H} - \widehat{H}^H X^H Y + \widehat{H}^H X^H X\widehat{H} \quad (3)$$

$$\frac{\partial J(\widehat{H})}{\partial \widehat{H}} = -2(X^H Y)^* + 2\left(X^H X\widehat{H}\right)^* = 0 \quad (4)$$

After the FFT, where the pilots are extracted from received OFDM symbols, the estimated channel response based on LS, $\widehat{H}_{LS}[k]$, express as [15]:

$$\widehat{H}_{LS}[k] = \frac{Y[k]}{X[k]}, \quad k = 0,1,2, \dots N-1 \quad (5)$$

Computing the Mean Square Error (MSE) of LS channel estimation is shown that MSE is inversely proportional to Signal to Noise Ratio (SNR), This means LS provides minimum error, i.e. performs best, at high SNR [4], [14].

IV. Channel Modeling

The channel referred to the path between transmitter and receiver which in that the signal passes. Determining the reception environment and its behaviour brings channel modelling. Types and scenarios of reception of the DVB-T are shown in Table II as it is in [5].

We will discuss about 4 types of channel models which are: Portable Indoor (PI), Portable Outdoor (PO), Rural Area reception (RA6) and Typical Urban reception (TU6) [16], [17]. In addition to these models, a Rayleigh channel which is a theoretical channel with 20 paths reflected signals with no speed and fixed receptions using a roof top outdoor antenna is employed [5], [16], [18].

TABLE II. DVB-T/H Transmission Channel Profiles [5]

Profile AWGN	Characteristics Noise channel	Paths all	Reception all
RC20	Ricean fading Without Doppler shift	20 All const. phase and without Doppler	Fixed
RL20	Rayleigh fading Without Doppler shift	20 All const. phase and without Doppler	Portable
Rayleigh	Rayleigh fading without Doppler shift	6 All is randomly realized with exponentials power delay profile with a dynamic range of 20dB	fixed
PI	Direct path and echoes with Doppler shift -speed 3km/h	12 All pure Doppler	Portable
PO	Direct path and echoes with Doppler shift -speed 3km/h	12 All pure Doppler	Portable
TU6	Rayleigh fading Urban area - speed 50km/h	6 Rayleigh	Mobile
RA6	Ricean fading Rural area - speed 100km/h	1 Ricean 5 Rayleigh	Mobile

A. Portable Indoor and Portable Outdoor

Portable is referred to devices which can move from one point to another. In this scenario the reception is not moving fast and it assumed maximum 3km/h. Wing-TV project has developed PI and PO channel models to define the slowly moving hand held reception indoors and outdoors [5], [16]. The amount of maximum delay in these two channels has made difference between them, which in PI its higher then PO model but the paths in PO channel have more attenuation. The Doppler spectra of various taps are defined in [19].

B. Rural Area Reception and Typical Urban Reception

Arguing about mobile receptions, bring the high speed movement above 50km/h. Mobile receptions are suffering from noise AWGN, multipath reception, narrowband interferers, impulse interferers and etc. following the channel variation in time and frequency beside noise handling , need a strong synchronization [5]. TU6 and RA6 reproduce the terrestrial propagation in an urban area and rural area respectively which in TU6 Doppler effect is half in comparison to RA6. TU6 has been defined by COST 207 as a typical urban profile and is made of 6 paths having wide dispersion in delay and relatively strong power [5]. By setting up the subcarriers in 2k mode, the high frequency brunt which made by Doppler shift in high speed, became minimized.

V. Simulation and Results

The simulations performed are intended for the 4, 16 and 64-QAM with 2k subcarriers which are shown in Fig. 2 to Fig. 4 receptively. The aim in the simulations is to rich a sufficient Bit Error Rate (BER) in a specific SNR interval. The simulation has been run for 5 different channels which their characteristics has been described in Table II and AWGN has been added to channels.

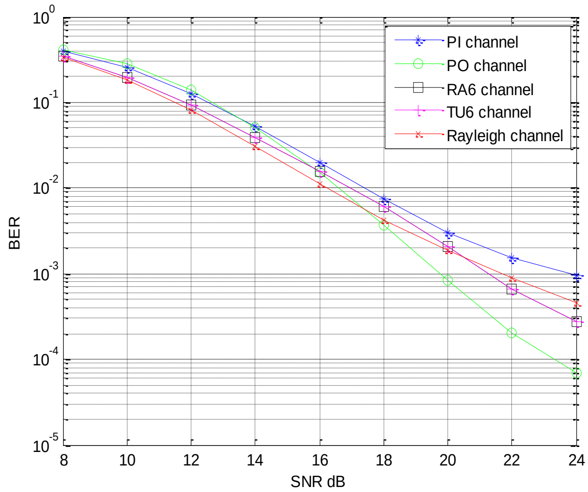


Figure 2. BER performance of 4-QAM channels

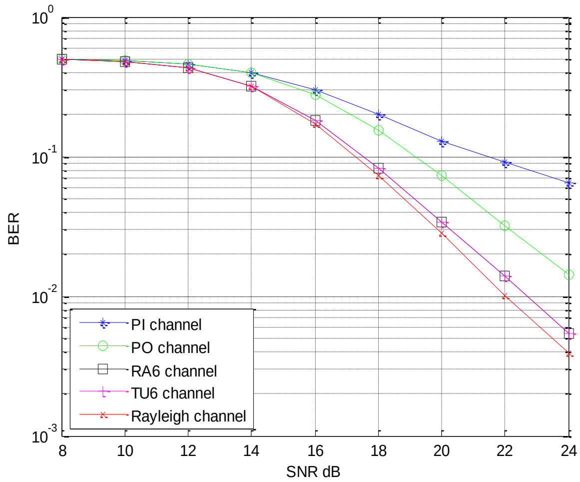


Figure 3. BER performance of 16-QAM in 5 different channels

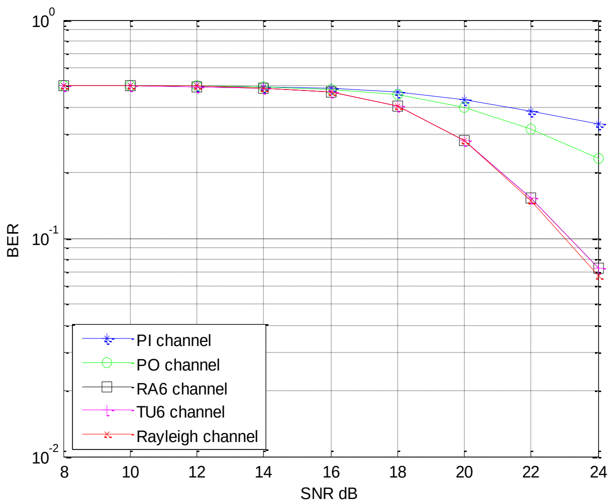
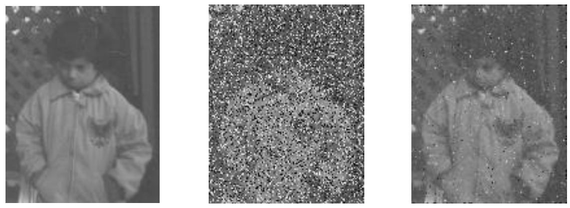


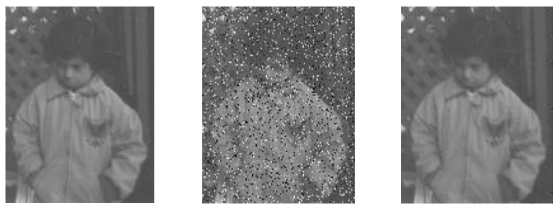
Figure 4. BER performance of 64-QAM channels

The BER performance has been measured after removal of energy dispersal in each 3 constellations. By setting up the guard interval to ¼, convolutional encode to ¾, FFT size to 2048, pilot spacing to 4 and number of frames to be transmitted to 2000 the following results has been achieved. As it was expected the 64-QAM has the worst operation between 3 constellations and it is obvious from simulated graphs that between assumed SNR interval, this constellation is useless. Also in high speed channel models we can reach a nearly sufficient result by increasing the SNR over 30dB and using median filter for clear the noise from received data which has been shown in Fig. 5, and the distortion is not critical. For 4 and 16-QAM the performance is much better in all 5 channels and with the usage of median filter we can reach an adequate BER performance in the receiver as the compression before and after median filter has been modified in Fig. 6 for 4-QAM in 14 dB SNR in PI channel which has the worst performance between all 5 channels.



Original Before median filter After median filter

Figure 5. Comparison of median filter in 64-QAM



Original Before median filter After median filter

Figure 6. Comparison of median filter in 4-QAM

In 4-QAM, PO channel has made a better performance over 18dB SNR by presence of one direct path, less attenuation paths than PI channel and low speed. In 16 and 64-QAM in an absence of direct path, using fixed receiver in Rayleigh channel has made the performance best among channels. For high speed channels TU6 and RA6, having at least one direct path has made a small improvement, e.g. in 20dB SNR the BER difference is 6.237808e-02 for 16-QAM. It explains that line of sight has more influence than Doppler shift.

VI. Conclusions

In this article, LS based channel estimation and detection has been implemented for DVB-T broadcasting and the systems performance is estimated through simulations using MATLAB. The transmitter, receiver and channel models are created with reference to relevant ETSI standards. Simulations have been performed for 3 different constellations in 5 different channel models. Transmission and reception of a standard image has also been simulated. The results have shown that by increasing the number of constellations, BER performance gets worse. This is caused by loss of orthogonality of the OFDM subcarriers due to the fast varying multipath Rayleigh fading channel conditions at high data rates. Hence, the absence of LOS in the channel has a detrimental effect even when the number of constellations reduced to 4 as in 4-QAM modulation. The use of a median filter seems to play an important role in clearing the raster in the received picture by eliminating the noise in the received signal. Sufficiently good performance is obtained at 20dB SNR while the transmission is in TU6 channel for 16-QAM. Investigating the simulation results revealed that, DVB-T broadcast systems based on 2k-OFDM has sufficiently good performance for 4-QAM whereas 16-QAM shows unacceptably low performance. However, by using a median filter after detection, the performance of even 16-QAM, seem to be acceptable for clear picture broadcasting.

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