

Adaptive Averaging Channel Estimation for DVB-T2 using Doppler Shift information

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Abstract—The problem of channel estimation for Orthogonal Frequency Division Multiplexing (OFDM) systems in fast time-varying and frequency selective radio channels has attracted the attention of scientists and receiver manufacturers. The wireless communication suffers from Additive White Gaussian Noise (AWGN), fading due to the multipath nature of the channel and spectral dispersion caused by the relative movement of the receiver with respect to the transmitter. In this paper a novel channel estimator for the Next Generation Terrestrial Digital Video Broadcasting (DVB-T2) is proposed. It is based on the estimation of the Doppler Shift (DS) from the variations of the envelope of the edge pilots (EP), in order to estimate the time interval where the channel could be considered as flat and then adaptively adjusting a buffer where the scattered pilots (ScP) carried within the received OFDM symbols during this time interval, are stored and averaged. Because the noise is considered AWGN with zero mean, the averaging process discards the noise and by interpolating the pilots an estimation of the channel is obtained.

Index Terms— Average, channel estimation, Channel modeling and simulation, Doppler estimation, Doppler shift, DVB-T2, Rayleigh, Next generation Broadcasting system, OFDM, pilots.

I. INTRODUCTION

NOWADAYS there is an increasing need for broadcasting video content in very high bit rates, in order to fulfill the demands of High Definition Television (HDTV) [1], and the upcoming Ultra High Definition TV (UHDTV) standards, [2]. For the terrestrial broadcasting, the Next Generation Digital Video Broadcasting DVB-T2, [3] standard, which uses Orthogonal Frequency Division Multiplexing (OFDM), [4], is able to support these challenges. In radio communication there are many degrading factors that reduce the system's throughput. The most common factors that degrade the quality of reception are the noise, the multipath nature of the radio channel and the frequency shifting caused by the relative movement between the transmitter and the receiver. The last two factors have a time and/or frequency varying impact that causes fading, [5]. The aim of the channel estimation is to find the channel frequency response $h(n, l)$ for the n^{th} subcarrier into the l^{th} received OFDM symbol and to apply a reverse function $h^{-1}(n, l)$ in order to restore the initial information. However, as the channel is not perfect,

the degrading factors introduced by the environment reduce the quality of reception. In this paper we consider the noise as Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 , $N \sim (0, \sigma^2)$. In [6], a simple to implement averaging channel estimator is proposed. The basic idea is to average the last few received OFDM symbols in order to discard the noise as it has zero mean. The estimator works acceptably for time invariant channels, however it is unable to follow variations in time because of its fixed buffer depth. In [7], a more sophisticated version of the averaging estimator is proposed, as it takes into account the relative speed of the transmitter and the receiver. The disadvantage of this approach is that the instantaneous speed has to be somehow known to the channel estimator. In this paper a novel averaging channel estimator is proposed. It can estimate the Doppler Shift (DS) by using the knowledge of the variation of the envelope of the Edge Pilots (EP) carried in every OFDM symbol of the DVB-T2 standard. In the literature there are a lot of proposals for an effective way to estimate the DS. In [8], the DS is estimated from the Phase Difference of the received pilot within an OFDM symbol. Other proposals for DS estimators are based on that the DS is relative to the fluctuations of the envelope of the received signal. Hence, the Level Crossing Rate (LCR) and the Zero Level Crossing (ZLC) are commonly used, which are based on the autocorrelation function of the received signal.

In [9], the autocorrelation of the received signal is used to estimate the DS, and in [10] the same approach of received signal's correlation is used and an extension is proposed that separates estimation of the DS for fast and slow time-varying channel environments. In [11] an improved DS estimator is proposed with adaptive Wiener filter coefficients. In [12], Holtzman & Sampath proposed an approximate expression for the DS estimator which uses the deviations of the envelope of the received signal which is logarithmically compressed. In [13], the same method as in [12] is used and a more accurate expression for DS estimation is proposed. A study of covariance-based estimators and LCR can be found in [14] which concludes that DS estimators of the literature converge at the same rate.

After the DS estimation, the channel response can be estimated using one of the proposed methods in the literature for DVB-T2 and OFDM in general. A Least Mean Error (LSE) Estimator with different pilot arrangement is given in [15], and the effect of pilot interpolation in time domain over

time-varying channels is analyzed in [16]. A DVB-T2 channel estimator for different Scattered Pilots (ScP) is modeled and evaluated in [17-18]. Additionally, a blind estimation is proposed in [19]. A comparative study for pilot assisted OFDM channel estimation with enhancement for DVB-T2 can be found in [20].

In this paper, a novel Adaptive Averaging Channel Estimator (AACE) for the DVB-T2 standard is proposed. It is based on averaging the last few received OFDM symbols, while the depth of averaging buffer is adaptively adjusted to the Doppler Shift (DS).

II. DOPPLER SHIFT ESTIMATION

In [9], a simple DS estimator is proposed by detecting the relation of time index z , which refers to the n^{th} received OFDM symbol, with the zero value at the zero-crossing point of the autocorrelation function $r(z)$, assuming that the channel behaves according to the Jake's model [21], where $z = n \cdot T_s$ and T_s is the OFDM symbol duration. So, we find the first OFDM index z where $r(z) < 0$ and consequently $r(z-1) > 0$. Now, $\hat{z}_0$ is the estimation of the first zero crossing point of $r(z)$ with linear interpolation as follows:

$$\hat{z}_0 = \frac{r(z)}{r(z-1) - r(z)} + z \quad (1)$$

The autocorrelation function of the received signal in time domain can be expressed as:

$$r(z) = J_0(2\pi f_D z T_s) \quad (2)$$

Where, $J_0(\cdot)$ is the Bessel function of zero order and of the first kind. We have that $r(z_0) = 0$ in (2) for:

$2\pi \hat{f}_D \cdot \hat{z}_0 \cdot T_s = 2.404826$. The estimated Doppler frequency $\hat{f}_D$ is then:

$$\hat{f}_D = \frac{2.404826}{2\pi \cdot \hat{z}_0 \cdot T_s} \quad (3)$$

Another DS estimation was proposed by Holtzman & Sampath, [12]. It calculates V as the squared deviation of the logarithmically compressed envelope of the received signal $y_i = 20 \log_{10}(x_i(t))$ sampled with period τ :

$$V = \frac{1}{N} \sum_{i=0}^{N-1} (y_{i+1} - y)^2 \quad (4)$$

where N is the number of the last considered samples. Now, $\hat{f}_D$ can be estimated as:

$$\hat{f}_D = \begin{cases} 15.25\sqrt{V}, & V < 3.8 \\ 4.033V + 19.60, & V \geq 3.8 \end{cases} \quad (5)$$

In [13], an improvement to the Holtzman & Sampath's DS estimator is proposed as:

$$\hat{f}_D = \begin{cases} \frac{(V + 0.796)}{41.664\pi}, & V \leq 1.087 \\ \frac{(V + 2.120)}{58.302\pi}, & 1.087 < V \leq 4.02 \\ \frac{(V + 4.789)}{77.3\pi}, & V > 4.002 \end{cases} \quad (6)$$

In Section V the DS estimator proposed in [9] is tested in depth and its performance is investigated in conjunction to the Adaptive Averaging Channel Estimator (AACE). Furthermore the DS estimator proposed in [12] is tested and its performance for different Signal to Noise Ratios (SNR) is discussed.

III. ADAPTIVE AVERAGING CHANNEL ESTIMATOR

The AACE proposed in this paper is based on the estimator proposed in [7]. A buffer of size $B \times k_{\max}$, is the key of the AACE, where $k_{\max}$ is the total number of subcarriers in every OFDM symbol and B is number of the last received OFDM symbols. The DS estimated in Section III is used to adjust the buffer size B . As the duration of each OFDM symbol is T_s [3], the buffer will be filled after time T_B equal to:

$$T_B = B \cdot T_s \quad (7)$$

Considering the channel frequency response as time invariant for a portion of time T_c , which is known as the coherence time, the channel suffers, for this period of time, only from the impact of noise. As the noise is considered AWGN with zero mean, an averaging process could discard the noise, thus a Least Square Error (LSE) equalizer could then be used to restore the received signal to its original state from a relatively noiseless estimation of the frequency response.

The coherence time T_c should be much larger than the buffering time T_B or $T_B \ll T_c$ because we need the channel to be almost flat in the time domain in order to apply effectively the averaging process. We set:

$$T_B = \frac{1}{25} T_c \quad (8)$$

The coherence time T_c can be set, [22]:

$$T_c = \sqrt{\frac{9}{16\pi \hat{f}_D}} = \frac{0.423}{\hat{f}_D} \quad (9)$$

where: $\hat{f}_D$ is the estimated Doppler Shift.

Combining (7), (8) and (9) we get:

$$B = \text{floor}\left(\frac{1}{50 \cdot \hat{f}_D \cdot T_s}\right) \quad (10)$$

In (10) the buffer size B must by default be: $B \geq 1$ so no value smaller than unity is used. Another assumption made is that if $\hat{f}_D$ is very small, B should not be extremely large, thus:

$$1 \leq B \leq 100 \quad (11)$$

The averaging process is described in (12):

$$avPilots(n) = \frac{1}{P_n} \sum_{i=1}^B A(i, n) \quad (12)$$

IV. CHANNEL MODELS

The radio channel has a destructive impact to the transmitted signal. The most common factors of distortion are the noise, the multipath, interference, and Doppler Shift (DS). In order to study and simulate these effects to the received signal a set channel models are used. For the Digital Video Broadcasting Terrestrial (DVB-T) the F1 (Ricean), and P1 (Rayleigh), [23], F6 (Ricean) and P6 (Rayleigh,) [24] were used. In this paper three new models from the Finnish Wing-TV test project, [25] will be used. They are based on real measurements and give realistic results. For simplicity in simulation, the Doppler spectrum in the first component of every model is assumed as Rayleigh-Jake. In Table I the definition of the Pedestrian Outdoor (PO), the Vehicular Urban (VU), and the Motorway Rural (MR) are given as a Power Delay Profile (PDP):

TABLE I
PDP OF THE PO CHANNEL PARAMETERS, [25]

	PO		VU		MR	
Path	Delay (μs)	Power (dB)	Delay (μs)	Power (dB)	Delay (μs)	Power (dB)
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.2	-1.5	0.3	-0.5	0.5	-1.3
3	0.6	-3.8	0.8	-1.0	1.0	-3.4
4	1.0	-7.3	1.6	-4.1	1.8	-6.8
5	1.4	-9.8	2.6	-8.8	2.5	-10.2
6	1.8	-13.3	3.3	-12.6	3.1	-12.9
7	2.3	-15.9	4.8	-18.6	3.9	-16.3
8	3.4	-20.6	5.8	-21.6	4.8	-19.5
9	4.5	-19.0	7.2	-24.6	5.5	-21.7
10	5.0	-17.7	10.8	-20.7	6.4	-23.3
11	5.3	-18.9	11.8	-18.8	7.0	-24.2
12	5.7	-19.3	12.6	-19.5	9.0	-25.8

V. SIMULATION AND RESULTS

A. Doppler Shift Estimation

The performance of the autocorrelation function for the DS estimation is tested for all three channel models described in Section IV. The configuration of the simulation is given in Table II.

TABLE II
CONFIGURATION OF SIMULATION

Parameter	Symbol	Value
FFT size	$k_{\max}$	2k
OFDM period	T_s	112μsec
Environment	-	PO,VU,MR
Doppler Shift	f_D	1, 10, 50, 120(Hz)
Doppler Buffer	L_{Buff}	100000
SNR	SNR	0,1,2,3,4,5 dB
Iterations		20

In Fig.1, the estimation for the Pedestrian Outdoor (PO) is shown, and in Table III the results of the simulation are given.

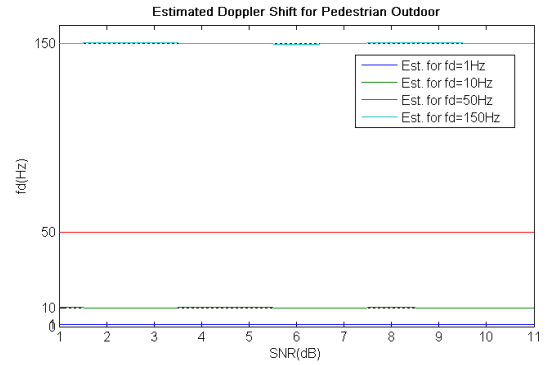


Fig.1. Estimated Doppler frequency for Pedestrian Outdoor.

TABLE III
SIMULATION RESULTS FOR PEDESTRIAN OUTDOOR

ACTUAL f_d (Hz)	ESTIMATED $\hat{f}_D$ (Hz)
1	0.990027
10	10.03165
50	50.1228
150	150.2709

In Fig.2, the estimation for the Vehicular Urban (VU) is shown, and in Table IV the results of the simulation are given.

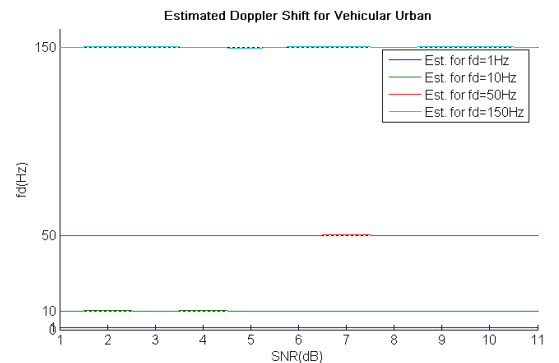


Fig.2. Estimated Doppler frequency for Vehicular Urban

TABLE IV
SIMULATION RESULTS FOR VEHICULAR URBAN

ACTUAL f_d (Hz)	ESTIMATED $\hat{f}_D$ (Hz)
1	0.9951
10	10.0064
50	50.06932
150	150.318

In Fig.3, the estimation for the Motorway Rural (MR) is shown, and in Table V the results of the simulation are given.

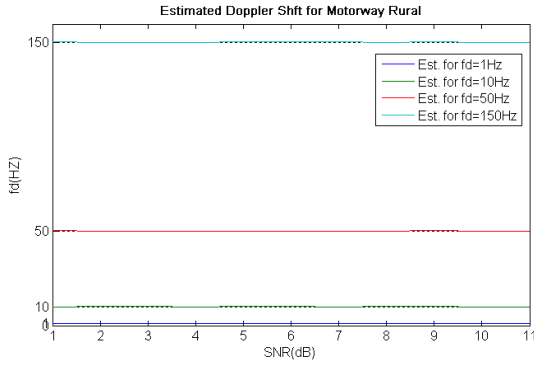


Fig.3. Estimated Doppler frequency for Motorway Rural.

TABLE V
SIMULATION RESULTS FOR MOTORWAY RURAL

ACTUAL f_d (Hz)	ESTIMATED $\hat{f}_D$ (Hz)
1	0.995636
10	10.04713
50	50.16589
150	150.31

The results of the simulations show that the estimated Doppler frequency $\hat{f}_D$ is independent of the SNR and the channel model.

When the Doppler frequency changes slowly in time, then the estimation of DS, can be calculated by the mean of the successive estimations. The accuracy of the estimation increases for larger Doppler frequencies and settles to the actual f_d value as the number of iterative estimations increases. In Fig.4, the results of different DS estimation with respect to the number of iteration are shown. Table VI shows the simulation results with $SNR = 0dB$, $T_s = 112\mu s$ for the Vehicular Urban channel model.

TABLE VI
SIMULATION RESULTS FOR DIFFERENT NUMBER OF ITERATIONS

Number of iterations	Doppler Shift f_d (Hz)			
	0.1	1	10	100
1	0.0823913	0.920326	9.6825	101.466
2	0.11184783	0.911304	9.922391	100.5589
3	0.13304348	1.008152	10.1712	101.3534
4	0.08673913	1.077717	10.21087	101.8449
5	0.12565217	0.967283	9.956848	100.0574
10	0.08836957	0.968804	10.09707	100.5253
20	0.10826087	0.98087	10.1013	100.8482
30	0.07891304	1.034891	10.14761	100.3774
40	0.10652174	0.994891	10.00174	100.8603
50	0.10891304	0.989457	10.01652	100.6328

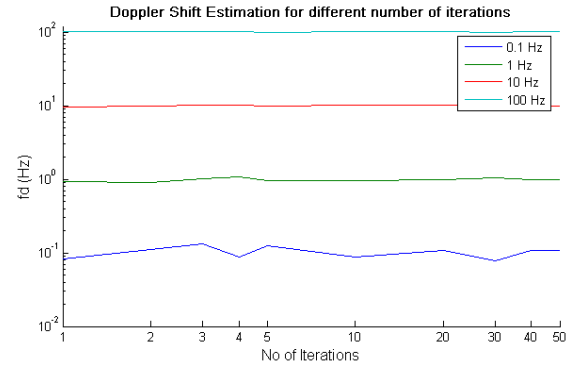


Fig.4. DS estimation for different number of iterations.

Finally the length L_{Buff} of the buffer $B_{Doppler}$ is a factor that affects the accuracy of the Doppler estimator. Using the Standard Deviation σ in (13), it is clear that as the L_{Buff} increases the σ decreases and the estimation converge to the expected (mean) value $\bar{f}_D$.

$$\sigma = \sqrt{\frac{1}{L_{Buff}} \sum_{i=1}^{L_{Buff}} (\hat{f}_{D_i} - \bar{f}_D)^2} \quad (13)$$

where $\hat{f}_D$ is the estimated DS and $\bar{f}_D$ the mean DS.

In Table VII the values of σ and $\bar{f}_D$ are given and in Fig.5 the graph of these parameters is depicted for $SNR = 0dB$, $T_s = 112\mu s$, $f_d = 2Hz$ and Vehicular Urban channel model.

TABLE VII
SIMULATION RESULTS OF STANDARD DEVIATION AND MEAN
VALUE OF DS FOR DIFFERENT BUFFER LENGTH

L_{Buff} (x1000)	σ	$\bar{f}_D$
20	0.491304	1.95
30	0.365109	1.977826
40	0.263043	2.016957
50	0.232717	2.004457
60	0.226196	2.006087
70	0.202935	2.032391
80	0.190326	2.013043
90	0.171304	1.980978
100	0.14413	2.024022
200	0.116848	2.017174
500	0.075435	2.019783

The performance of the Doppler estimation based on Holtzman & Sampath's proposal, [10] is depicted in Fig. 6. It is clear that for noisy channels this method is unacceptable, however for noiseless channels this method could be used as the computation load is very low.

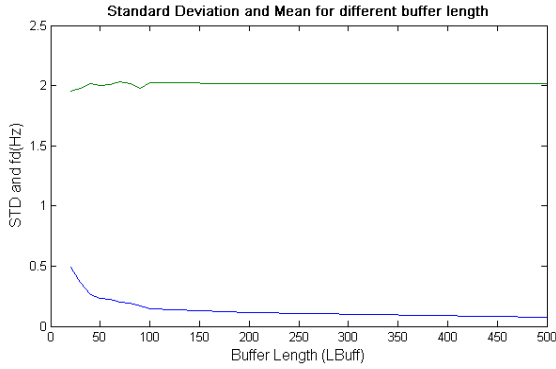


Fig.5. STD (σ) and Mean $\bar{f}_D$ for different L_{Buff} .

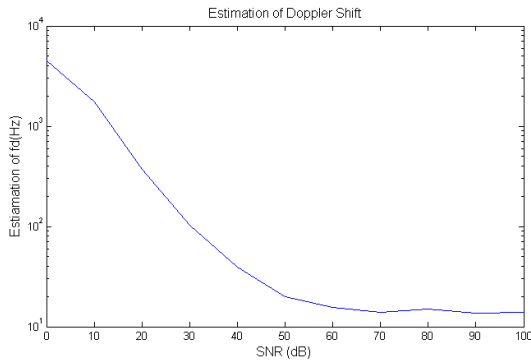


Fig.6. Doppler estimation based on Holtzman & Sampath's proposal.

B. Channel Estimation

The estimated value of DS $\hat{f}_D$ is now passed to the buffer

B_D which described in section III, and the resulting Bit Error Rate (BER) curves with respect to Signal to Noise Ratio (SNR) are depicted. The radio frequency of the RF signal is set to 800MHz and the bandwidth of the baseband signal is set to 8MHz. the Quadrature Amplitude Modulation (QAM) is 4-QAM, i.e. QPSK, and the FFT size is set to 2K. For a better study of the Adaptive Averaging Channel estimator (AACE) performance, neither interleaving methods are used, nor any channel coding technique.

In Fig.7, the performance of the proposed AACE is compared to a conventional non-averaging estimator. The channel model is set to Pedestrian Outdoor (PO) and the mobile speed to 3Km/h.

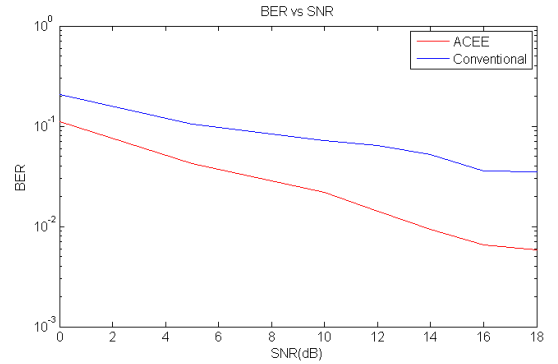


Fig.7. Performance comparison for AACE and conventional estimator using PO channel model and speed of 3Km/h.

In Fig.8, the performance of the proposed AACE is compared to a conventional non-averaging estimator. The channel model is set to Vehicular Urban (VU) and the mobile speed to 30Km/h. In Fig.9, the performance of the proposed AACE is compared to a conventional non-averaging estimator. The channel model is set to Motorway Rural (MR) and the mobile speed to 100Km/h. These simulations indicate that the performance of the proposed AACE compared to the conventional non-averaging estimator is better.

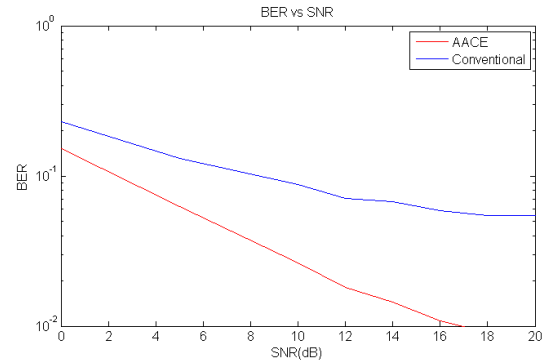


Fig.8. Performance comparison for AACE and conventional estimator using VU channel model and speed of 30Km/h.

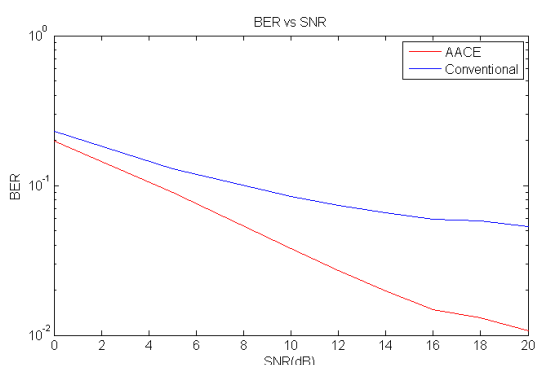


Fig.9. Performance comparison for AACE and conventional estimator using MR channel model and speed of 100Km/h.

VI. CONCLUSIONS AND FURTHER WORK

The performance of the Doppler Shift estimator based on the autocorrelation of the received signal has been tested systematically and its accuracy for different simulation configurations has been presented. The method based on the deviations of the envelope of the received signal as a metric of the DS is acceptable only for noiseless channels, and therefore its utility is limited. The proposed Adaptive Averaging Channel Estimator (AACE) achieves satisfactory operation in conjunction with the autocorrelation method for Doppler Shift. The low implementation complexity of the proposed AACE, and the minor memory and processing power requirements, makes the estimator an attractive choice for implementation in low-cost devices.

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