PERFORMANCE EVALUATION OF A DVB-T2 MOBILE SYSTEM USING A NEW TIME-VARIANT FIR CHANNEL

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ABSTRACT

The second generation terrestrial digital television standard DVB-T2 was standardized in 2009. When evaluating the overall performance of such communication systems, different channel models are used to model different reception scenarios. Commonly used channel models are AWGN, Rayleigh, Ricean, and TU-6. However, since each of the models simulate a specific reception scenario, it is difficult to ascertain the realistic overall performance of the system. In this paper, we introduce a simple channel model using a time-variant FIR filter. The FIR filtering is based on mobile field measurements obtained in Helsinki, Finland, in 2010. We apply FIR filtering on the measurement results in order to replicate a real time-variant channel model which enables performance evaluation of the DVB-T2 system in a mobile environment. Based on the time-variant FIR filter channel model, we simulate the performance of the DVB-T2 system, and show that there is a small performance loss when the channel conditions vary in time.

1. INTRODUCTION

When designing communication systems, a performance evaluation of the system is necessary in order to find potential flaws and to improve the design. The performance evaluation is normally done through extensive system simulations, using different channel models for simulating the signal propagation scenario and the noise interference. Some commonly used channel models are Additive White Gaussian Noise (AWGN), Rayleigh, Ricean [1], and Typical Urban 6-tap (TU-6) [2]. Although these channel models give performance assessments for specific signal propagation scenarios, they do not provide sufficient information for channels where the receivers experience heavily varying channel conditions which are typical for mobile receivers. In terms of signal propagation scenarios and noise interference, a mobile receiver may during a relatively short time interval experience direct line of sight to the transmitter antenna, high and low Doppler frequencies due to receiver movement and angle to the transmitter, shadowing from the transmitter, fast and slow fading of the signal [3], etc.

In this paper we propose to use a channel model for performance evaluation of mobile systems. The channel model is based on channel sounding carried out in Helsinki, Finland in 2010. A time-variant Finite Impulse Response (FIR) filter is applied on the data obtained from the channel sounding in order to mimic the channel conditions experienced during the channel sounding.

The paper is outlined as follows. Section 2 presents background to channel models and to the time-variant FIR channel model used in the performance evaluation. Section 3 discusses the channel sounding performed in Helsinki with necessary background, and gives the details about the FIR channel model used in this paper. Section 4 discusses the DVB-T2 standard and how the simulations are performed, while the simulation results are presented in Section 5. Section 6 concludes the paper.

2. TIME-VARIANT FIR CHANNEL MODEL

When wireless communication systems are developed, one essential part of the development environment is the availability of suitable channel models. The most essential channel is the AWGN channel, i.e., a channel where Gaussian noise is added to the signal. In a simulator environment, the AWGN channel gives some basic information of the systems resistance to noise. However, a channel with only additive noise is typical for systems with a line of sight (LOS) component only, corresponding for instance to a satellite system. For any terrestrial system, non-line of sight components are always present, as the signal is reflected from objects on the way from the transmitter to receiver. If the receiver is moving, the reflected components are also subject to Doppler frequency shifts, producing a Doppler spread. This behavior is modeled with the Rayleigh and Rice channel models, using assumptions on the statistical model for providing this Doppler spread.

A discrete multipath channel can be described, following the notation in [4], as

$$y(t) = \sum_{k=1}^{K(t)} a_k(\tau_k, t) s(t - \tau_k(t)) \tag{1}$$

where $y(t)$ is the output signal from the channel, $a_k(\tau_k, t)$ is a complex number describing the multipath attenuation at time t for echo k, and $\tau_k(t)$ is the multipath delay at time t. The general format for a FIR filter in a noise-free scenario is

$$y[k] = \sum_{n=1}^{N} h_k[n] x[k-n] \tag{2}$$

where $y[k]$ is the output samples, $h_k[n]$ is the FIR filter kernel coefficients, and $x[n]$ are the input samples. The format for the discrete multipath channel is quite general, but if we fix the number of available taps $K(t) = K$ and let $\tau_k(t)$ take values of the format nT_s, where T_s is the sampling time of the system, the channel can easily be implemented by a convolution calculation. When the filter kernel length is restricted to small values ($N < 20$), the simulation speed of the system is increased. Now the time-variant FIR channel model can be given by

$$y[k] = \sum_{n=1}^{N} h_k[n] x[k-n] + W_k \tag{3}$$

which means that at each time sample instant k a new FIR filter h_k will be used, and W_k is additive Gaussian noise, enabling simulations. This approach is similar to previous work, e.g., for simulations in indoor industrial environment [5].

The FIR channel model has been criticized by some authors, e.g. [6], for its lack of real performance evaluation, when channel estimation is to be included in the simulation environment. For performance simulations however, perfect channel estimation is often assumed, and hence this aspect is not so important.

The motivation for applying a time variant FIR filter is that simulations are commonly made using fixed representations of the multipath channel model. This gives good reproducibility when comparing and developing the different components of a communications system. Such simulations give good information on the system performance in static reception conditions, e.g., when using roof-top antennas. However, when the DVB-T2 standard is developed for mobile usage, and especially for handheld reception, the effects of time varying channels are yet open. The DVB-T2 system has quite long time interleaving, i.e., resistance against fading, but the real system performance in mobile usage is still to be investigated. Using the time variant FIR model, based on real-world channel soundings, gives the opportunity to analyze system performance for real mobile usage. Additionally, different settings and parameters in the DVB-T2 standard can easily be analyzed. Furthermore, the effect of adding additional interleaving depth, by additional coding, can be analyzed.

The FIR filter coefficients were acquired from the channel sounding given in section 3. As the channel varies rather slowly compared to the sampling frequency ($7/64\,\mu$s, for an 8 MHz DVB-T2 channel), long simulations were required in order to see the impact of the channel variations in the results.

3. CHANNEL SOUNDING

The channel model is based on channel sounding measurements carried out in Helsinki Finland during June-July 2010. The measurement campaign was a group effort by Amphenol, BBC, Digita, Elektrobit (EB), Nokia corporation, Tampere University of Technology (TUT), and Turku University of Applied Sciences (TUAS). The main idea was to measure the channel responses with two orthogonal polarizations in the transmitter and receiver sides using practical antennas in order to find MIMO channel characteristics. The transmitter antennas were located on the YLE Pasila/Helsinki transmitter tower at about 112 m above the ground and the receiver antennas at different outdoor and indoor locations around the transmitter tower. The distances between receiver and transmitter were typically about 2 km.

The portable receiving station consisted of the EB channel recorder, cross-polar application antenna (at approximately 1.5 m) and batteries for powering the equipment. The campaign resulted in about 300GB of data from about 100 measurement cases (locations and receiver antenna combinations).

Here we concentrate on the Single-Input and Single-Output (SISO) -case and typical outdoor conditions. In the data analysis, it was found that eight multipath taps describe sufficiently the time-variant multipath behavior of the channel in this case. The power delay profile of the channel is defined by

$$h(t,\tau) = \sum_{k=1}^{8} g(t,\tau_k)\delta(\tau - \tau_k) \tag{4}$$

where k is the tap number, $g(\cdot)$ is the gain, τ is the delay in time, and $\delta(\cdot)$ is the Dirac delta function. The channel parameters are as shown in Table 1.

Due to the small velocities during the measurements, in order to allow the performance evaluation with different mobility, emerging Doppler behavior is modeled by applying tap-wise Doppler spectra as given in Table 2, in which

$$S(f, f_d) = \begin{cases} \frac{1}{\pi f_d \sqrt{1-(f/f_d)^2}}, \text{when} |f| < f_d \\ 0, \text{otherwise} \end{cases} \tag{5}$$

Table 1: Power delay profile of the 8-tap outdoor model

Tap number, k	**Excess delay,** τ_k (μs)	**Tap power gain,** (dB)
1	0	-4.0
2	0.1094	-7.5
3	0.2188	-9.5
4	0.6094	-11
5	1.109	-15
6	2.109	-26
7	4.109	-30
8	8.109	-30

Table 2: Doppler spectrum characteristics of the outdoor model

Tap number, k	**Doppler spectrum**
1	LOS only, no additional Doppler shift
$2 \dots 3$	$S\left(f - \frac{3f_d}{4}, \frac{f_d}{4}\right)$
$4 \dots 8$	$S\left(f + \frac{3f_d}{4}, \frac{f_d}{4}\right)$

is the classical Jakes Doppler spectrum [3] with maximum Doppler frequency of f_d (Hz).

In particular, we concentrate on the case with 40 Hz Doppler corresponding to a velocity of 15 m/s, when the frequency is 800 MHz. Figure 1 illustrates the relative power of the resulting 8-tap model as a function of the sample index at the DVB-T2 elementary sampling time of $7/64\mu$s. As can be seen, taps 2–8 vary greatly over time, while tap 1 is constant.

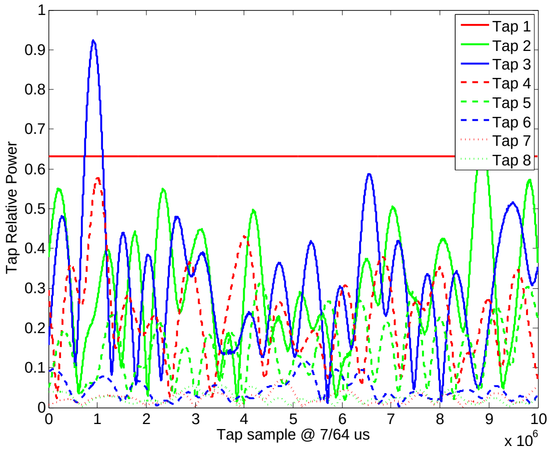

Figure 1: Relative power of taps as function of sample index at DVB-T2 elementary sampling time of $7/64\mu$s.

4. DVB-T2 SIMULATION ENVIRONMENT

The time-variant FIR channel model is applied to a DVB-T2 system [7] for performance evaluation. The DVB-T2 system is the second generation standard for transmission of terrestrial television. As compared to its predecessor DVB-T, which is widely adopted around the world, DVB-T2 has a more efficient physical layer using state-of-the-art technologies to achieve close to optimal performance in terms of true bit-rate in quasi-error free transmissions: concatenated LDPC and BCH coding, rotated high-order QAM constellations, MISO (Multiple Input Single Output) antenna reception, efficient time and frequency interleaving, large FFT sizes, etc. All in all, DVB-T2 can give an increase in capacity (bit rate) of at least 30% as compared to DVB-T, and for some configurations up to 70% [8]. An interesting aspect of DVB-T2 is its potential for providing service-specific robustness at the physical layer. Each service is assigned to a physical-layer pipe (PLP) and each PLP can have a modulation, code rate and time interleaving length of its own.

A conceptual block diagram of the relevant parts of this study of the transmitter side of the DVB-T2 system is illustrated in Figure 2. DVB-T2 uses several different mechanisms to provide diversity, which is necessary for improving the overall reception quality. Time diversity is achieved through the bit interleaver, cyclic Q-delay combined with QAM constellation rotation, cell interleaver, and time interleaver. Frequency diversity on the other hand is achieved through the frequency interleaver, while spatial diversity is obtained through the MISO scheme. Additionally, DVB-T2 includes the option for using Time Frequency Slicing (TFS) to achieve both time and frequency diversity. Because of these mechanisms, the DVB-T2 system is tolerant against fast and slow fading effects, and even against signal erasures, due to the cyclic Q-delay combined with the QAM constellation rotation.

The implementation of the DVB-T2 system is made in C/C++. The software is optimized in many respects and gives close to real-time performance. However, to achieve this throughput speed, some simplifications are used, the most notable being the use of perfect channel estimation. In a hardware implementation, the channel conditions have to be estimated at the receiver in order to decode received information correctly. This is done by inserting pilots with known amplitude and phase in the transmitted signals. The pilots are inserted with a certain pattern (in time and frequency), which is known to the receiver. Each receiver can then estimate how noise has affected the signals using two-dimensional interpolation. This results in an approximate channel characterization. With perfect channel estimation, the interpolation step is omitted, and instead received information is compared to the transmitted data in order to characterize the channel conditions. The net effect of perfect channel estimation is an assessment on the best possible performance of the system. Also, since the two-dimensional interpolation is computationally complex, using perfect channel estimation is common praxis when simulating the performance of communication systems.

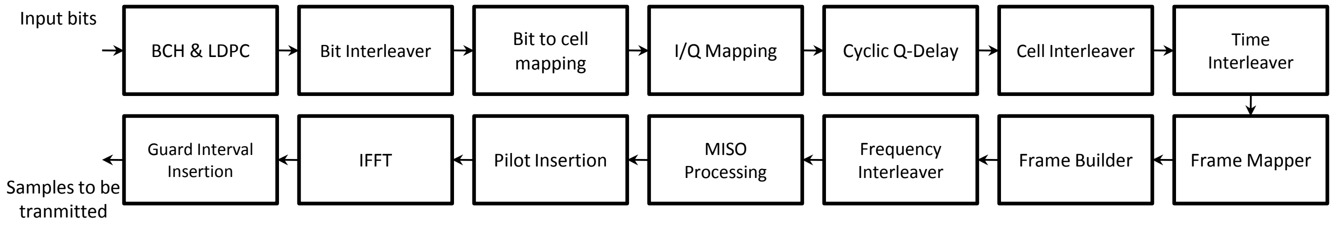

Figure 2: Block diagram of the DVB-T2 modulator.

5. SIMULATION RESULTS

The performance of the DVB-T2 systems over the time-variant FIR channel model is simulated with the following settings. A single PLP is used where the physical layer code rate is $1/2$ with 64800 bits LDPC codewords, the time interleaver length is the maximal 250 ms, and all supported QAM modulations are used. The FFT size is 8k, and the guard interval is $1/4$. TFS is not used, and the transmission scenario is SISO. For each SNR, the simulations were run until either 20 erroneous FEC frames had been accumulated after decoding, or until 2000 FEC frames had been decoded. The reasoning behind this stopping criterion is related to the steepness of the waterfall regions in the BER curves, i.e., for low SNRs the decoded BER will be high on average. On the other hand, as soon as the SNR reaches a certain threshold, the BER will drop quickly with small increases in the SNR, thus requiring longer simulation runs for obtaining reliable estimates on the system performance.

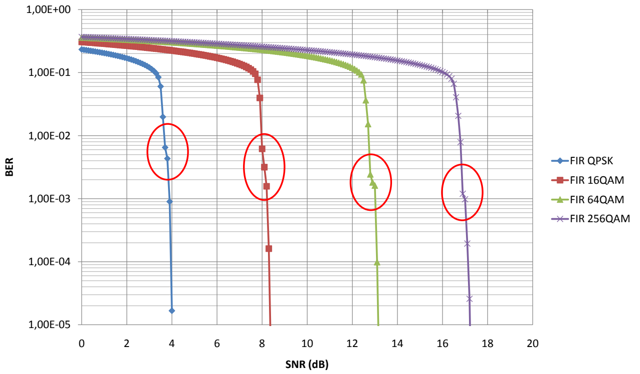

Figure 3: DVB-T2 system performance on the FIR channel model

Figure 3 illustrates the DVB-T2 system performance on the FIR channel model for the different modulations. As can be seen, the bit error rate (BER) drops quickly when a sufficient SNR level is reached. This trend in the BER curve is typical for DVB-T2 systems. However, the red circles in Figure 3 mark the regions where the waterfall curve differs from the normally expected performance, where a small error floor is experienced. When comparing Figure 3, to Figures 4 and 5, where the performance is compared to the performance from the Ricean (F1) and Rayleigh (P1) channels, it is also evident that quasi-error free (QEF) performance is achieved at approximately 1–2 dB higher SNRs.

The requirement on a higher SNR on the FIR channel can be explained by the fact that the channel conditions vary over time. Due to the long time interleaving of DVB-T2, FEC frames will contain data from both good and bad reception conditions. This results in the LDPC decoder having to iterate more before finding the correct codeword, as compared to the case when FEC frames contain either good or bad information. Since in practical implementations, and also in this simulator, the maximum number of decoding iterations is limited, the decoder may not find the correct codeword before it has performed the maximum number of iterations. This clearly results in a non-zero BER in the decoded codeword, and hence on average a higher BER.

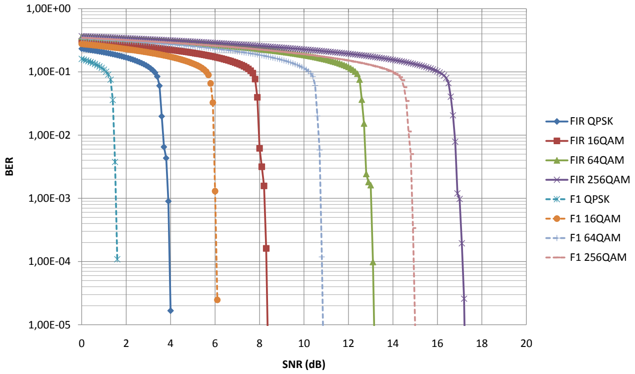

Figure 4: DVB-T2 system performance on the FIR channel model vs the F1 channel model.

Figure 6 shows the BER for each decoded FEC block from a simulation run corresponding to the reception of data during approximately 3 minutes with QPSK modulation and SNR 4 dB. The 1000-point moving average of the individual FEC block BERs is also illustrated to better show how the

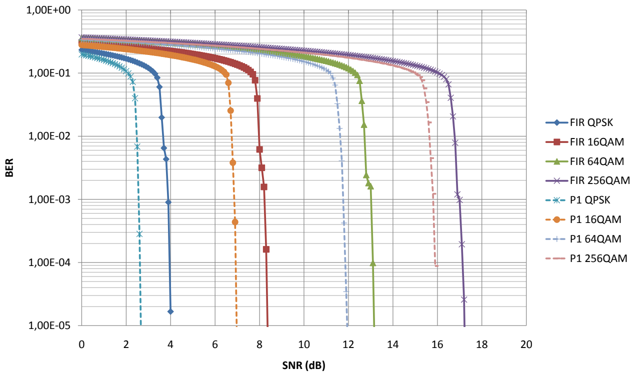

Figure 5: DVB-T2 system performance on the FIR channel model vs the P1 channel model.

performance varies in time. As can be seen, the BER in each block varies greatly between the FEC frames. More specifically, in approximately the first 7000 FEC blocks, there are only occasional block errors and with relatively small BERs. In the following 14000 FEC blocks, the frequency of the block errors increases along with the decoded BERs in the blocks. This is followed by a smaller average BER in blocks 21000–240000, whereafter the frequency of the block errors increases slightly again. While it may not be evident from Figure 6, the majority of the FEC frames are error free, resulting in an average BER over all FEC frames of $1.7 * 10^{-5}$.

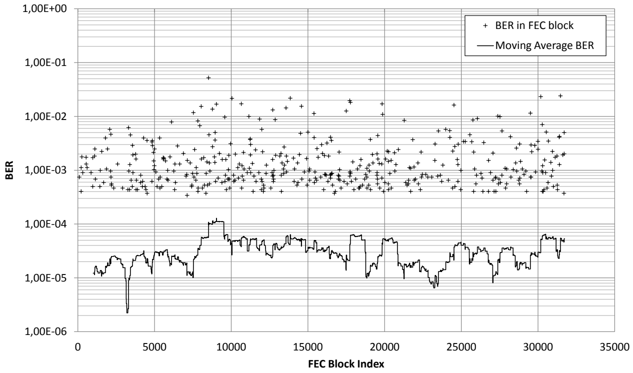

Figure 6: BER for individual FEC blocks along with a 1000-point moving average BER at SNR 4 dB for QPSK modulation, corresponding to a reception time of approximately 3 minutes. The average BER is $1.7 * 10^{-5}$.

6. CONCLUSIONS

This paper presents results on using a time varying FIR channel model in DVB-T2 simulations. The FIR channel was based on channel soundings performed in the city of Helsinki, Finland. The aim was to get information on the performance of the DVB-T2 system in a scenario that better corresponds to real mobile channel conditions than statically defined channels. Especially varying tap strengths was believed to affect the simulation results.

For each simulation case, the FIR channel model shows worse performance for all simulated DVB-T2 system parameters. The results are not surprising, though. It is very likely that, due to shadowing, the real world performance of a mobile DVB-T2 system is worse than the static channel scenarios described in the standards. What in this study was noted, however, was a quite varying per FEC block error ratio in the waterfall region of the system.

It is noteworthy that the gain of the strongest tap was normalized. This is not the case in a mobile scenario, where the strongest path will vary greatly in time. The work is in progress for also analyzing scenarios where the tap gain of the strongest tap is not normalized, such that greater time variability is obtained. This will give more information on how the time interleaving of the DVB-T2 system will work for mobile scenarios. In the future, studies will also include analysis of the MIMO case.

7. REFERENCES

[1] ETSI EN 300 744 v1.6.1. Digital Video Broadcasting (DVB); Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television (DVB-T). European Telecommunication Standard Institue, 2009.

[2] COST 207. Digital Land Mobile Radio Communications (Final Report). Commision of the European Communities, Directorate General Communications, Information Industries and Innovation, 1989.

[3] W.C. Jakes. *Microwave mobile communications*. IEEE Press, 1994.

[4] Michael Jeruchim, Philip Balaban, and Sam Shanmugan. *Simulation of Communication Systems, Second Edition: Modeling, Methodology and Techniques*. Kluwer Academic Publishers, 2000.

[5] U. Trautwein, G. Sommerkorn, and R.S. Thoma. A simulation study on space-time equalization for mobile broadband communication in an industrial indoor environment. In *1999 IEEE 49th Vehicular Technology Conference*, volume 1, pages 511–515, July 1999.

[6] Jianhua Liu. Be cautious when using the fir channel model with the ofdm-based communication systems. *Vehicular Technology, IEEE Transactions on*, 58(3):1607 –1612, March 2009.

[7] ETSI EN 302 755 v1.2.1. Digital Video Broadcasting (DVB); Frame Structure Channel Coding and Modulation for a Second Generation Digital Terrestrial Television Broadcasting System (DVB-T2). European Telecommunication Standard Institue, 2011.

[8] L. Vangelista, N. Benvenuto, S. Tomasin, C. Nokes, J. Stott, A. Filippi, M. Vlot, V. Mignone, and A. Morello. Key Technologies for Next-Generation Terrestrial Digital Television standard DVB-T2. *Communications Magazine, IEEE*, 47(10):146–153, Oct. 2009.