On the Performance of Multiple OFDM Receivers for DVB

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Abstract

Due to its robustness to multi-path propagation conditions and support for high data rates, Coded Orthogonal Frequency Division Multiplexing (COFDM) has become one of the more popular modulation techniques for indoor and outdoor broadband wireless data transmission [1]. OFDM has been adopted in many wireless worldwide standards such as wireless LAN 802.11a/g, HIPERLAN/2, Digital Audio Broadcasting (DAB), Digital Video Broadcasting Terrestrial (DVB-T), Digital Video Broadcasting for handheld (DVB-H), 802.16, and Broadband Wireless Access. In this paper we present the performance of the Sandbridge Technologies' DVB-T software implementation for mobile applications for both a single receiver and multiple receivers. In our software implementation, the DVB-T protocol can coexist with other communication protocols including GSM, 3G UMTS, and GPS.

1. Introduction

In multi-path environments, an OFDM receiver may exhibit poor Bit Error Rate (BER) performance. To improve the BER of the OFDM receiver, in addition to inherited frequency diversity, time and coded diversity may be added through sophisticated interleaving and channel coding. Spatial diversity can further be applied to an OFDM system to achieve significant performance improvements in fading environments. Spatial diversity can be achieved by adding multiple antennas at the transmitter and receiver, leading to Multiple-Input Multiple-Output (MIMO) systems [2].

This paper is organized as follows. In Section 2 we describe the signal and channel model employed throughout the paper. In Section 3 we describe the various system block diagrams and simulation results of a single input 2k DVB-T system. We then extend it to multiple inputs. In Section 4 we present system results of our DVB-T design. We then make implementation and concluding remarks in Section 5 and Section 6, respectively.

2. Signal Model

An OFDM transmitted signal for a DVB-T communications protocol can be described in mathematical format by the following formula [3]:

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi f_c t} \sum_{m=0}^{\infty} \sum_{l=0}^{67} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \Psi_{m,l,k}(t) \right\} \qquad (1)$$

with:

$$\Psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_U}(t-\Delta-l\times T_s-68\times m\times T_s)} & (l+68m)T_s \le t \le (l+68m+1)T_s \\ 0 & else \end{cases}$$

Where: k is the carrier number, l is the OFDM symbol number, m is the transmission frame number, K is the number of transmitted carriers, Ts is the symbol duration, f_c is the central frequency of the RF signal, k' is the carrier index relative to the central frequency, $k'=k-(K_{max}-K_{min})/2$, $c_{m,0,k}$ is the complex symbol for carrier k of the data symbol number 1 in the frame number m, $c_{m,1,k}$ is the complex symbol for carrier k of the data symbol number 2 in the frame number m, an so on $c_{m,67,k}$ is the complex symbol for carrier k of the data symbol number 68 in the frame number m.

The impulse response of the channel is described by:

$$h(t) = \sum_{t=l}^{N_{p-1}} c_l(t)\delta(t-\tau_l) \qquad (2)$$

where: δ is the delta function, $c_l(t)$ are the time varying complex channel coefficients, and τ_l are the path delays.

The received base-band signal will be the convolution of the transmitted signal with the channel impulse response plus a noise term:

$$\int_{-\infty}^{+\infty} s(t)\sum_{t=0}^{N_{p-1}} c_l(t)\delta(t-\tau_l)dt + \mathbf{n}(t) \qquad (3)$$

In formula (3), n(t) is the noise term including the thermal noise and the in-band interference, and N_p is the number of statistically independent paths.

3. System Description

The block diagram of a generic DVB-T transmitter is shown in Figure 1.

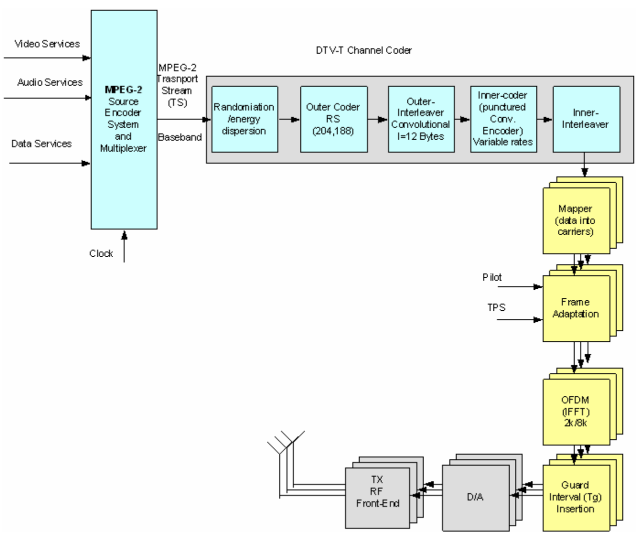

Figure 1 DVB-T generic transmitter block diagram.

The transmitted signal described in formula (1), convolved with the impulse response of the channel described in formula (2) is received by the receiver described in Figure 2.

The receiver includes all the blocks specific to OFDM receivers: coarse and fractional frequency recovery, frequency tracking, timing recovery and tracking, channel estimation, tracking and correction, QAM symbol de-mapping. The block diagram of the base band processing for the 2k DVB-T receiver is illustrated in Figure 3.

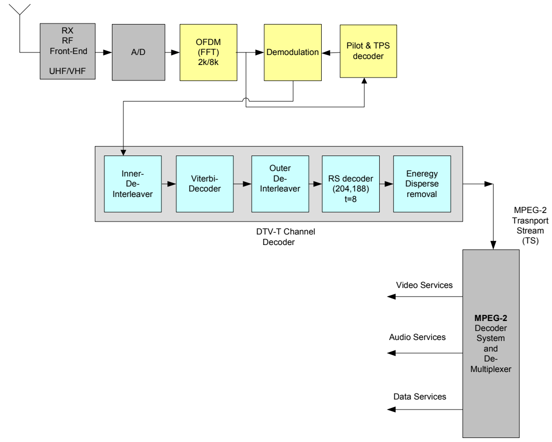

Figure 2 Generic DVB-T receiver block diagram.

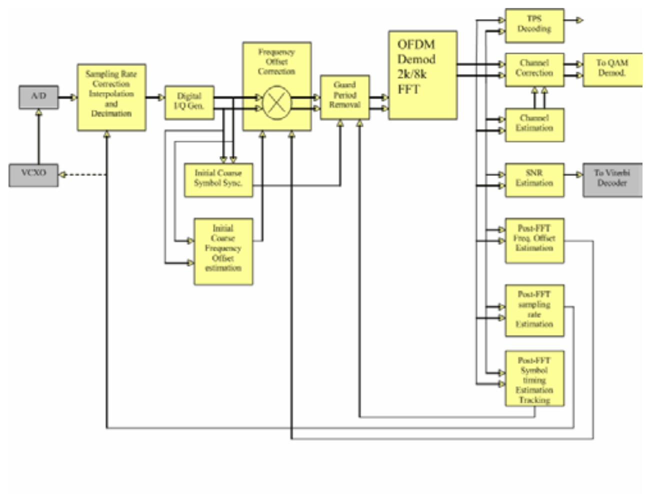

Figure 3 2k DVB-T block diagram.

Extension to MIMO systems

The OFDM receiver can be extended to multiple input paths by adding additional single input receivers. Each receive channel requires a separate RF antenna with analog front-end circuitry and partially separate signal processing channel. Each receiver channel must independently perform separate timing synchronization frequency offset estimation, correction, and channel estimation.

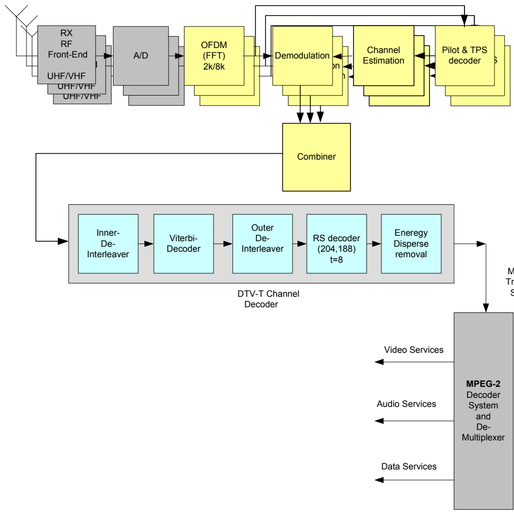

Figure 4 Multiple input receiver block diagram.

Figure 4 shows a DVB-T receiver with spatial diversity. A single input DVB-T receiver may perform poorly in the presence of Non-Line-Of-Sight (NLOS) fading radio channels. By coherently combining the received signal from multiple receiver branches the SNR can be lowered for the same BER.

Adding more than two receivers (besides the associated increased cost) also causes another undesired effect - the mutual coupling of the antennas [4]. The mutual coupling is significant when the antennas are placed in each other's near field as is the case of hand held devices. In order to correct for the coupling effect of the antennas, a matching network needs to be added to the front end. On the other hand the matching network will mitigate some, if not all, of the expected performance improvement because of the increased insertion loss, deteriorating the overall performance/cost of the receiver. A good compromise is to use only two receivers with mutually orthogonal antennas.

In our design, the relative placement of the two antennas has been chosen experimentally. Two multi-band antennas, as described in [5], have been used in the experiment. First we measured the S_{11} parameter of a single antenna from 0 to 3 GHz. Then we placed a second antenna in the near field of the first antenna at a distance equal to a fraction of the wave length. In the same frequency band we measured the S_{11} parameter of the first antenna placed parallel to the second antenna in the same plan. We repeated the same measurement with the antennas placed perpendicular in two perpendicular plans.

The experimental results for the two different placements are shown in Figure 5.

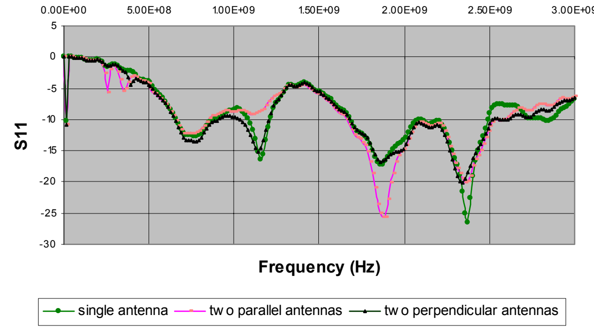

Figure 5 Measurement results for the placement of two multi-band antennas.

As confirmed in Figure 5 if the two antennas are perpendicular, the coupling between them is negligible. In this particular case, for our simulation model, we can approximate the receive channels as uncorrelated.

The block diagram of the two channel receiver is illustrated in Figure 6.

In Figure 6, the RF signals coming from the antennas are separately amplified and then fed into a phase shifter controlled by the baseband processor. The phase shifter shifts the incoming waveform with a specific angle, determined by the signal processor, in such a way that the signals from the two antennas are combined coherently.

The placement of the two antennas on the hand held device is illustrated in Figure 7.

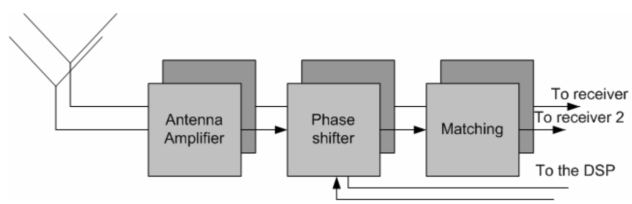

Figure 6 The receiver front end using two separate receive channels.

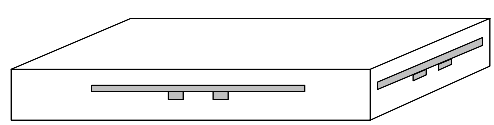

Figure 7 The placement of the two antennas on the hand held device.

4. Numerical Results

The simulation conditions were as follow: statistically independent paths, ideal channel, two bit Soft Input Hard Output (SIHO) Viterbi decoder with Channel State Information (CSI), hard input Reed Solomon decoder. Generally speaking, more receivers will provide lower SNR for Quasi Error Free (QEF) receiving at the cost of increased receiver complexity. Further improvement can be achieved using higher de-mapping bit resolution and soft Reed Solomon decoder.

The simulation results for different channel conditions and channel models for Single Input Single Output (SISO) as well as MISO Multiple Input Single Output (MISO) configuration are shown in TABLE 1. and Figure 8. In TABLE 1 the performance numbers required by the ETSI EN 300 744 V1.4.1 (2001-01) standard are also shown.

From the simulation results it can be seen that as we add more receivers the total required SNR for QEF receiving decreases in an asymptotic fashion. The highest gain is achieved by adding the second receiver and as we add more receivers the added gain is less. For instance, a second receiver for the QPSK Gaussian channel mode will add a 2.89 dB gain, while the third receiver will add only 1.34 dB. In reality, because the third antenna will be coupled to the other two antennas, the total gain will be smaller.

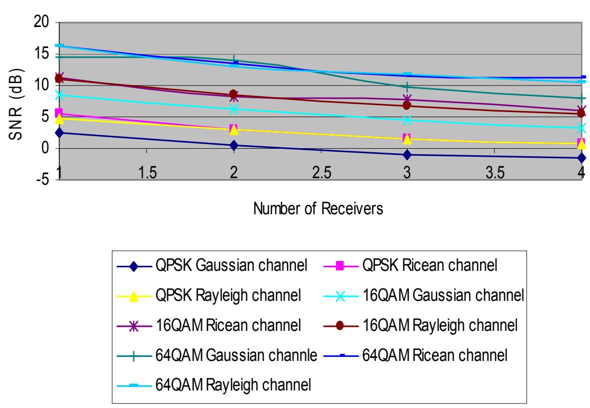

Figure 8 Multiple channel simulation for different channel conditions and models.

5. Implementation

The entire simulation, for both the receiver and transmitter, have been implemented in double precision C and fixed point C.

The real time implementation is targeting the Sandbridge Technologies Software Defined Radio development platform based on the Sandbridge multi threaded Digital Signal Processor [1].

6. Conclusions

In this paper we presented the simulated performance results of the 2k DVB-T. We showed that for a MIMO system applicable to a hand held device the best performance/cost approach is employing two receivers with uncoupled antennas.

TABLE 1 Simulated performance for different test cases specified in [3]Annex A.

	Required C/N for QEF After RS Decoder (AnnexA) Gaussian channel	Simulated C/N for QEF After RS Decoder 1 Receiver	Simulated C/N for QEF After RS Decoder 2 Receivers	Simulated C/N for QEF After RS Decoder 3 Receivers	Simulated C/N for QEF After RS Decoder 4 Receivers
Modulation	Gaussian channel	Gaussian channel	Gaussian channel	Gaussian channel	Gaussian channel
QPSK Rate 1/2	3.1 dB	2.61 dB	0.43 dB	-0.91 dB	-1.41 dB
16QAM Rate 1/2	8.8 dB	8.47 dB	6.24 dB	4.61 dB	3.23 dB
64QAM Rate 1/2	14.4 dB	13.90 dB	11.01 dB	9.83 dB	7.96 dB
Modulation	Ricean channel	Ricean channel	Ricean channel	Ricean channel	Ricean channel
QPSK Rate 1/2	3.6 dB	5.58 dB	2.93 dB	1.59 dB	0.83 dB
16QAM Rate 1/2	9.6 dB	11.25 dB	8.14 dB	7.79 dB	6.03 dB
64QAM	14.7 dB	16.20 dB	13.45 dB	11.60 dB	11.25 dB
Modulation	Rayleigh channel	Rayleigh channel	Rayleigh channel	Rayleigh channel	Rayleigh channel
QPSK Rate 1/2	5.4 dB	4.87 dB	2.93 dB	1.59 dB	0.83 dB
16QAM Rate 1/2	11.2 dB	11.01 dB	8.47 dB	6.65 dB	5.58 dB
64QAM Rate 1/2	16 dB	16.26 dB	13.07 dB	11.71 dB	10.51 dB

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