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ABSTRACT

In this paper we present the system and software implementation of the Digital Video Broadcasting protocol for hand held applications (DVB-H), on the Sandbridge Technology's multithreaded digital signal processor SB3011. The I and Q base-band analog output signals from the tuner are digitized, filtered and further processed conforming to ETSI EN 302 304 V1.1.1 (2004-06). All processing blocks including the receiver synchronization and forward error correction are executed entirely in software. At 1.5 Mbps the processor usage is less then 40% with maximum power consumption of 120mW.

Keywords: SDR, DVB-H, digital video broadcasting

1. INTRODUCTION

Digital Video Broadcasting [1] is an OFDM system[3] directly compatible with MPEG-2 coded TV signals. It operates in the existing 6, 7, and 8MHz VHF and UHF spectrum allocation for analog TV transmission. A new 5MHz channel was added for DVB-H [2]. DVB-T operates in 2K and 8K modes while DVB-H has a third mode, 4K. The 8K mode is used for small, medium and large Single Frequency Networks (SFN) providing the lowest Doppler shift tolerance but highest bit rate transmission. The 4K mode can be used for small and medium SFN, with less Doppler shift tolerance while the 2k mode can be used for small SFN with limited range providing the best Doppler shift tolerance at high speed and high data rates. Thus, the 4k mode is a compromise between transmission rate, range, and Doppler shift. Multiple programs, data, video and audio are multiplexed together into a transport stream as shown in Figure 1. The DVB system supports two hierarchical levels of channel coding and modulation and, uniform and multi-resolution constellation. The hierarchical nature is restricted to channel coding and modulation only, allowing the simulcast of a program service (or different programs) at different bit rates and different transmission ruggedness. The MPEG frames are split into high and low priority streams. The two separate streams are randomized separately, passed through the outer coder, outer interleaver and inner coder and then inner-interleaved together. After mapping and frame adaptation the data is OFDM modulated, the guard is appended, the data is converted from the digital to analog domain and passed to the transmitter. The input stream is organized in 188 byte MPEG-2 packets including one synchronization byte. The data is randomized using a PRBS generator and further, encoded. DVB employs concatenated Reed-Solomon RS(204, 188, t=8) and 64 state convolutional encoder, with the polynomials: $G_1=171_{OCT}$ and $G_2=133_{OCT}$. At the link layer DVB-H has a second RS encoder followed by virtual time interleaving for the purpose of improving the overall mobile system performance. Data in each OFDM frame is modulated using QPSK, 16-QAM, 64-QAM, non-uniform 16-QAM or non-uniform 64-QAM constellations. Details of the encoders, interleavers and constellations for both hierarchical and non-hierarchical mapping are described in the standard [1]. Conceptually the DVB-H is DVB-T backwards compatible as shown in Figure 2. The Time-Slicing in DVB-H is a burst transmit mechanism which assures lower average power consumption by reducing the total time the receive chain or parts of it are powered, at the cost of much lower average bit-rates then the DVB-T. It also provides cell ID identification and seamless service handover in mobility situations. During a burst, the receiver stores the high rate bit stream and then while parts of the receiver are in idle mode it processes and streams the data to the display at lower, seamless playback, bit-rate. Due to the Time-Slicing the total storage space for a DVB-H terminal becomes an issue. Conforming to the standard, the highest duty factor percentage (active versus inactive time) is 14%. Another important characteristic of DVB-H is that the payload are IP-datagrams or other network layer datagrams encapsulated into MPE sections.

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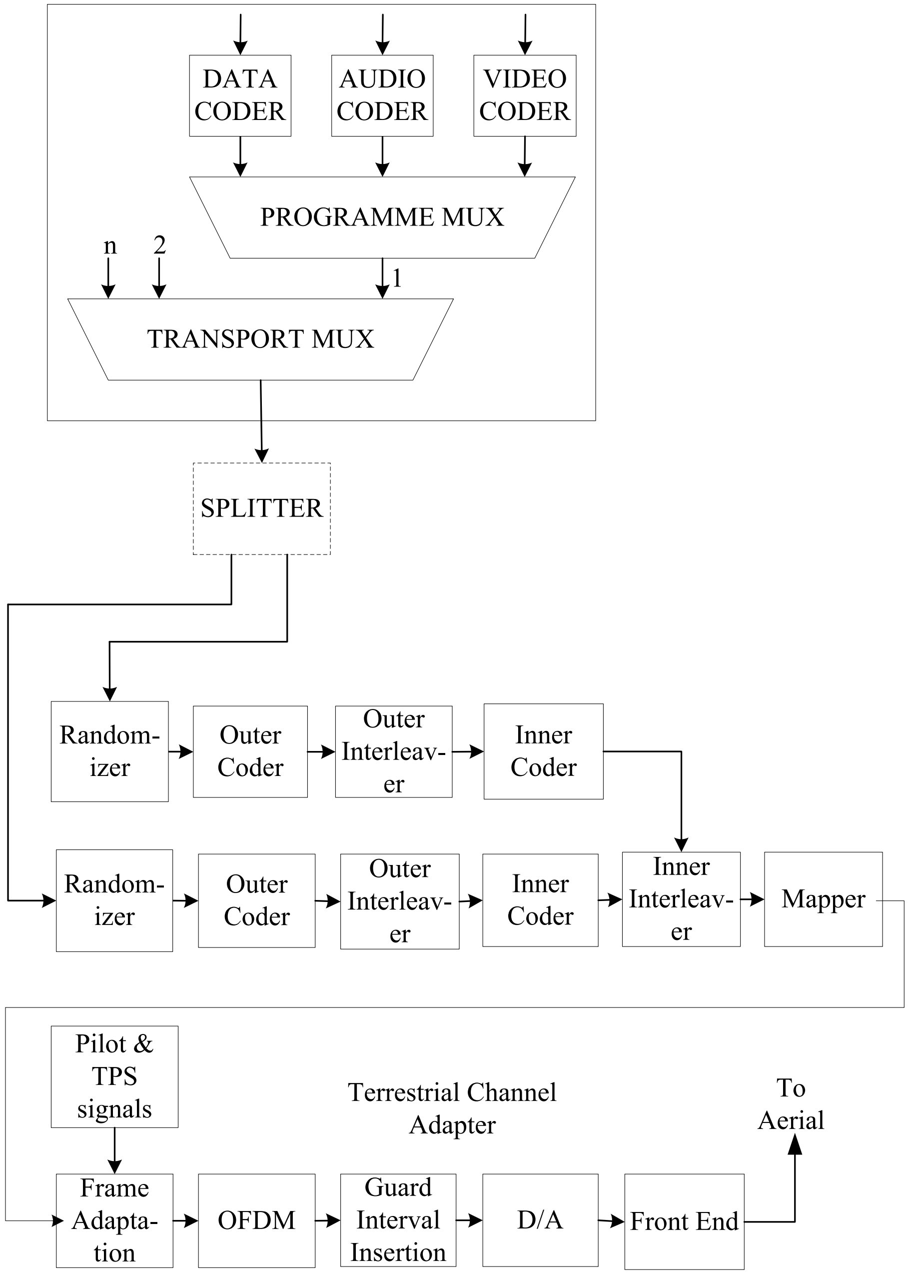

Fig. 1. Transmitter processing chain.

The DVB-H transmission is organized in frames and super frames. Each super-frame includes four frames and each frame contains 68 OFDM symbols. Each OFDM symbol contains a predefined number of carriers depending on each operation mode. There are dedicated data, system information and pilot carriers. The pilots are used for receiver synchronization and channel equalization and they carry reference signals known by the receiver at increased power level. There are continual and scattered pilots. The continual pilot's positions coincide with the scattered pilot positions every four symbols with values derived from a PRBS generator.

The system information includes modulation, hierarchy information, code rate, guard interval etc. System information is carried by the Transmission Parameter Signaling (TPS) carriers. DVB-H allows extra signaling carried by the TPS carriers to enhance the service and cell ID discovery as well as faster signal scan and frequency handover. The TPS carriers are DBPSK modulated and encoded using BCH (67, 53, t=2) derived from the original BCH (127, 113, t=2) code. The system parameters for the three modes of operation are listed in Table 1.

Table 1. System Parameters for 8MHz Channel.

Mode	2K	4K	8K
Number of carriers K	1705	3409	6817
K_{min}	0	0	0
K_{max}	1704	3408	6816
Carrier spacing (Hz)	1116	2232	4464
Freq. spacing between K_{min} and K_{max} (MHz)	7.61	7.61	7.61
Useful Symbol Duration (μs)	224	448	896
Guard ratio	1/4, 1/8, 1/16, 1/32	1/4, 1/8, 1/16, 1/32	1/4, 1/8, 1/16, 1/32

2. DVB-H IMPLEMENTATION

As described before, since DVB-H has lower average data rates then DVB-T, it can be implemented entirely in software and executed in real time in the SB3011 DSP. DVB-H receiver processing chain is illustrated in Figure 3. Briefly, the processing blocks perform the following functions: The de-rotation function performs fine frequency correction through complex multiplication of the received digitized samples with certain pre-calculated complex values. Pre-Processing (PP): the DVB-H receiver functions expect f_c=32/7MHz for the Low Intermediate Frequency (LIF) and f_s=4f_c for the sampling frequency. The PP function adjusts f_c and f_s if the LIF frequency and sampling rate are not what the receiver expects. The Guard Length Detection (GLD) function detects one of the guard lengths used by the transmitter. Further, the coarse fractional offset is estimated and corrected in the Coarse Fractional Frequency Offset Estimation and Correction (CFFOEC) block followed by Coarse Symbol Synchronization (CSS) and Integer Frequency Offset Estimation and Correction (IFOEC). After the Guard Removal (GR), Fine Frequency and Timing Estimation and Correction (FFTEC) take place during steady state operation right after the OFDM demodulation. The Symbol Synchronization Tracking (SST) uses timing information from the Burst Timing Power Manager (BTPM) and provides the complex values to the de-rotation block. Large frequency correction is achieved by changing the RF chip PLL configuration. Channel Estimation and Correction (CEC) will also provide the Channel State Information (CSI) required by the Viterbi and TPS decoders in the Inner Processing (IP) and TPS decoding block respectively. In our implementation, all these processing blocks are executed completely in software. Both RS decoders, in the Outer Processing (OP) and MPE-FEC processing blocks, are also executed in software using Galois field multiplication vector instructions.

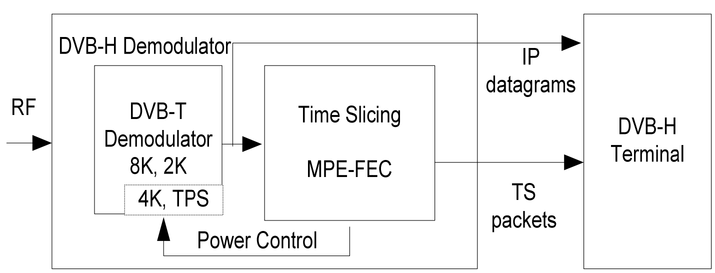

Fig. 2. DVB-H theoretical structure

In the sequel we briefly describe the main software functions: The ExtractRxSubcarriers function performs the subcarriers extraction and calculates the Channel Transfer Function (CTF) on the scattered pilot locations for the current two OFDM symbols. The first time the ExtractRxSubcarriers function is called there is no symbol synchronization. The OFDM starting symbol position is found at the cross-correlation peak position. The scattered pilot starting position re-search for the current OFDM frame is also needed the first time when ExtractRxSubcarriers is called due to the fact that there may have been corrections for integer frequency offset resulting in change of scattered pilot locations.

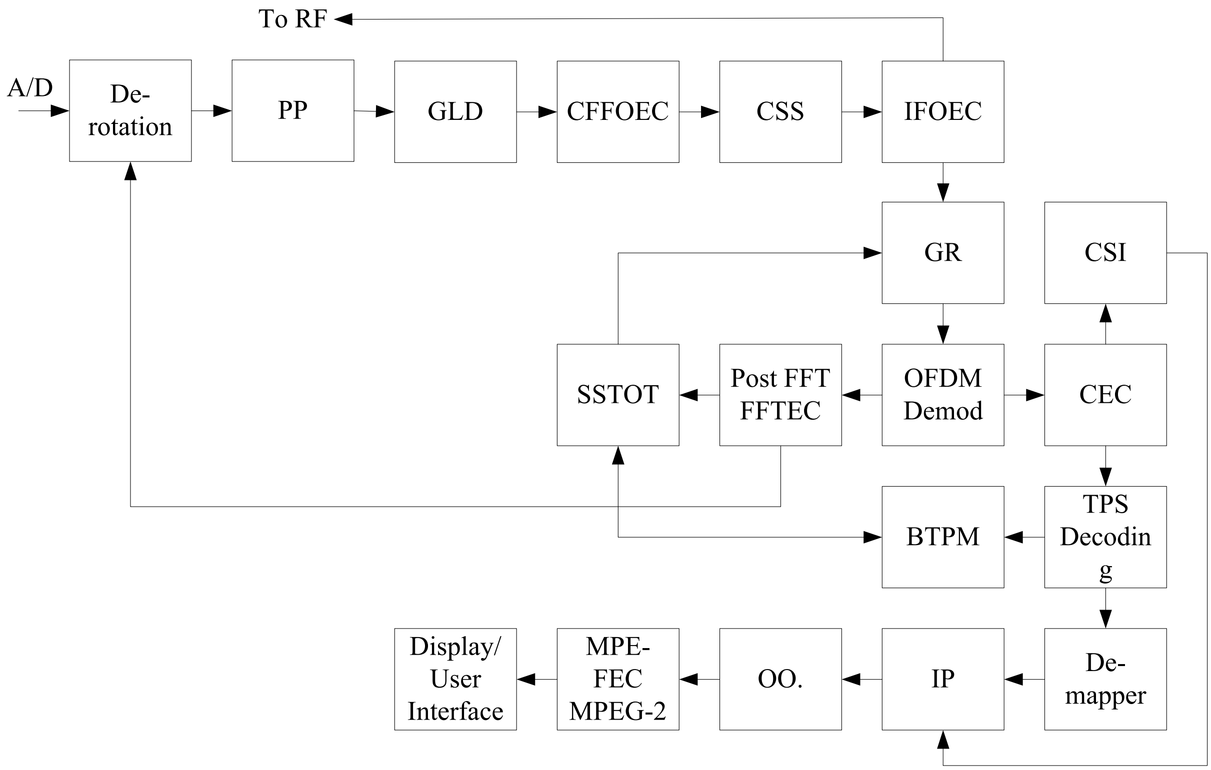

Fig. 3. DVB-H receiver functional block diagram.

The ChannelEstimation function performs channel estimation and correction for the current OFDM symbol, based on the scattered pilots. For each OFDM symbol, the scattered pilots are spaced 12 subcarriers apart. First, the CTF samples on the scattered pilot positions for the current OFDM symbol are estimated. Second, interpolation for 3 virtual pilot groups is performed. The CTF estimates for the current symbol on the virtual pilots, spaced 3 subcarriers apart, are obtained through interpolation of the previous 3 symbols and future 3 symbols. Then, the remaining two CTF samples between each virtual pilot pair, for the current symbol, are estimated. As soon as the CTF samples are estimated, the channel correction is performed to get the corrected received subcarriers, further used by the QAM demapper and TPS decoding. CTF estimates are also used to calculate the Channel State Information (CSI), values acting as estimates of reliability measure for each subcarrier. Currently, the CSI is estimated as the amplitude of the CTF at each subcarrier frequency. The CSI is used in the Viterbi decoder as a weighting factor for the path metrics calculation so that the input soft bits that are less reliable will contribute less to the path metrics accumulation. The CSI is also used as a weighting factor in TPS DBPSK demodulation and decoding to assure that the less reliable TPS carriers have less contribution in the estimation process [6].

The next function, FracOffsetTracking, performs steady state fractional carrier frequency offset tracking based on estimating the average phase difference between two pilots located in two consecutive OFDM symbols at the same frequency. In order to smooth the estimated phase difference information an averaging window of configurable length is used. The steady state symbol synchronization tracking based on estimating the averaged phase differences between neighboring scattered pilot subcarriers is performed by SymbolSyncTracking function. It is called per each OFDM symbol and an averaging window of configurable length is applied to smooth the estimated phase difference information. SymbolSyncIntOffset performs a coarse OFDM symbol synchronization first followed by OFDM demodulation. A 4K FFT is performed to extract the subcarriers for pilot detection [5]. In the pilot detection routine, the first step is to search for scattered pilot locations by exploiting the fact that for each OFDM symbol, the scattered pilots are located 12 subcarriers apart, and they are transmitted at a boosted power level. The second step is to search for the continual pilots. The continual pilots are transmitted at fixed subcarrier locations, also transmitted at a boosted power level. The continual pilots are spaced at multiples of three carriers from the scattered pilots. The search range for the continual pilot starting position determines the range of the integer carrier frequency offset that the receiver is designed to cover. Finally, GuardLenCoarseFracOffset detects the guard length and performs coarse fractional frequency offset estimation. First, is generates a virtual complex sample sequence from the real input sample sequence. Then 4 cross-correlations are performed on the complex sample sequence. For each cross-correlation sequence, we estimate the corresponding distance between the two peak positions and then the 4 distances are compared with the 4 valid guard lengths. The guard length that is closest to any of the distances will be selected as the valid guard length. Once the guard length is detected, the phase difference between the guard period and the corresponding symbol period is calculated giving a coarse estimate of the fractional carrier frequency offset. There are several receiver states, from cold start to steady state operation, the receiver transitions during operation, as illustrated in Figure 2.

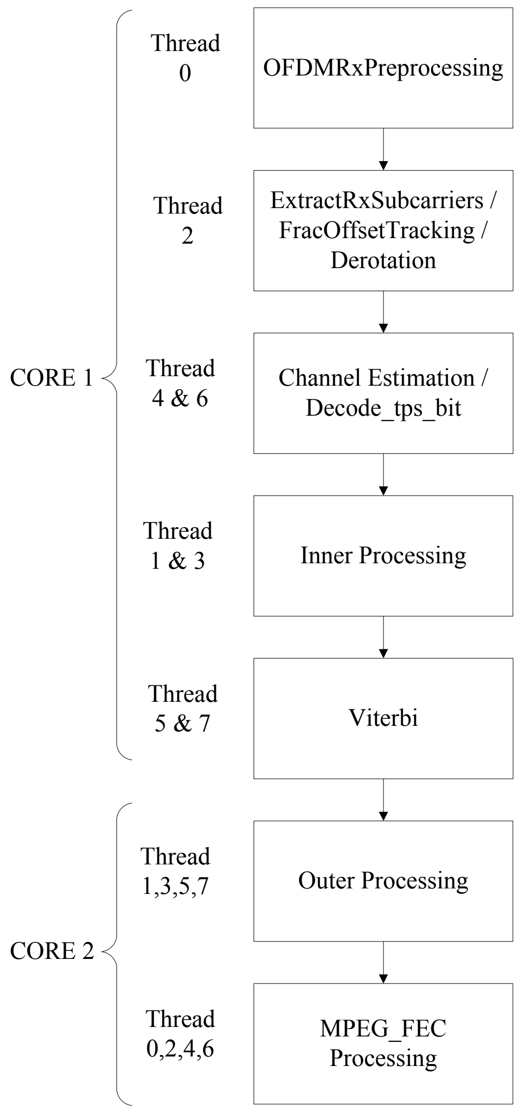

Fig. 4. Receiver state transitions.

Right after power is switched ON, the receiver starts with State 0. The receiver will perform Guard Length Detection (GLD) and Coarse Fractional Frequency Offset Detection and Correction (CFFODC) during this state. To improve the robustness of the detection algorithm in the presence of noisy and fading channel, a majority detection of guard length is performed. Coarse fractional frequency offset estimation is also estimated and corrected for, once the guard length is detected. It follows State 1 in which the receiver performs OFDM Initial Coarse Symbol Synchronization (ICSS), Continual / Scattered Pilots Detection (C/SPD) and Integer Frequency Offset Estimation Detection (IFOED) and correction. First, a cross-correlation is performed on the received sample sequence, assuming the guard length is known, which will produce a rough estimate of the OFDM symbol sampling position. Then, the OFDM symbol is extracted and demodulated (i.e. 2K FFT for 2K mode) to recover the subcarriers. Since continual pilots are located at fixed carrier locations, they are detected first while scattered pilot locations are detected next. As in the case of guard length detection, majority detection is also performed for pilot detections. In the process of continual pilot detection, integer carrier frequency offset is also estimated and corrected for. After this state, the receiver will idle in State 2 in order to remove any transient effects after the frequency adjustments. In State 3 the receiver starts steady state Fractional Carrier Frequency Offset Tracking (FCFOT) using the tracking continual pilots. The receiver will stay in this state for a number of OFDM symbols until frequency offset tracking converge. State test is used only during testing and calibration. The receiver performs continuously the fractional carrier frequency offset tracking and starts OFDM Symbol Synchronization Tracking (SST) in State 4. The receiver stays in this state for a programmable number of OFDM symbols to allow any residual symbol synchronization offset to converge. The steady state is State 5. In this state the receiver performs Continual Fractional Carrier Frequency Offset Tracking (CFCFOT), and Continual Symbol Synchronization Timing Offset Tracking (CSSTOT) to keep the frequency and timing in sync with the transmitter. Also, channel estimation and correction is performed in this state. If the receiver looses synchronization, it will transition back to State 0. Among all the states, only States 3, 4 and 5 require real time processing.

The entire physical layer has been implemented on the Sandbridge Technologies DSP, SB3011 [4,7]. Based upon measured computational performance the thread allocation is as depicted in Figure 5. The usage of the SB3011 is less then 40 % for 14% duty cycle. The simulated performance for various channel conditions, as described in the [1] ANEXA A is presented in Table 2.

Table. 2. DVB-H simulated performance.

	Required C/N in dB for QEF after Reed-Solomon Decoder	Required C/N in dB for QEF after Reed-Solomon Decoder	Required C/N in dB for QEF after Reed-Solomon Decoder
Modulation Mode	Gaussian Channel	Ricean Channel	Rayleigh Channel
QPSK rate ½ Simulated Performance from Annex A in DVB-T	3.1dB	3.6dB	5.4dB
QPSK rate ½ 1 rx channel	2.61dB	5.58dB	4.87dB
QPSK rate ½ 2 rx channels	0.43dB	2.93dB	2.93dB
QPSK rate ½ 3 rx channels	-0.91dB	1.59dB	1.59dB
QPSK rate ½ 4 rx channels	-1.41dB	0.83dB	0.83dB
16QAM rate ½ Simulated Performance from Annex A in DVB-T	8.8dB	9.6dB	11.2dB
16QAM rate ½ 1 rx channel	8.47dB	11.25dB	11.01dB
16QAM rate ½ 2 rx channels	6.24dB	8.14dB	8.47dB
16QAM rate ½ 3 rx channels	4.61dB	7.79dB	6.65dB
16QAM rate ½ 4 rx channels	3.23dB	6.03dB	5.58dB
64QAM rate ½ Simulated Performance from Annex A in DVB-T	14.4dB	14.7dB	16.0dB
64QAM rate ½ 1 rx channel	13.90dB	16.20dB	16.26dB
64QAM rate ½ 2 rx channels	11.01dB	13.45dB	13.07dB
64QAM rate ½ 3 rx channels	9.83dB	11.60dB	11.71dB
64QAM rate ½ 4 rx channels	7.96dB	11.25dB	10.51dB

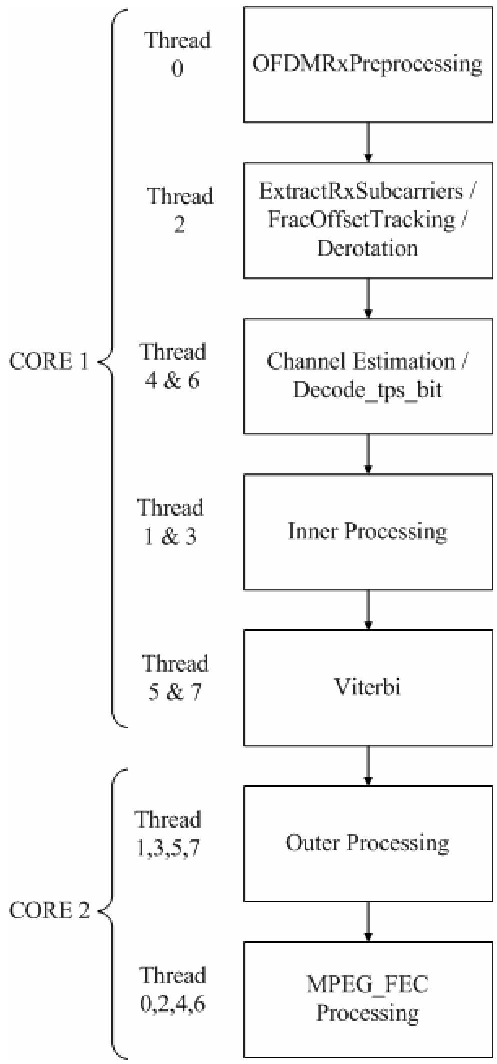

Fig. 5. SB3011 thread allocation.

3. CONCLUSIONS

The entire DVB-H execution requires only 50% of SB3011 processor resources at the highest bit rates and modulation complexity. An additional 60% of processor capacity is still available to execute other functions [8]. When implemented on the recently announced SBX core, the expected utilization will drop to less than 10% of the capacity [9].

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