The ISDB-T Multiplex Frame Pattern Explained

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***Abstract*—ISDB-T defines the so-called *Broadcast Transport Stream*, an MPEG transport stream adapted to carry hierarchical information. This BTS is created in the transmission side, but it has to be perfectly recovered in reception. To that end there is an algorithm defined in the standard which we found not clear regarding the implementation. We also found the bibliography regarding this algorithm was poor. After our experience implementing *gr-isdbt*, the first open, free and software-based ISDB-T receiver, fully implemented in GNU Radio, we were able to understand this algorithm and decided to describe it step by step from the implementation point of view.**

I. Introduction

In previous works [1], [2], we have presented *gr-isdbt*, the first open, free and software-based ISDB-T receiver, fully implemented in GNU Radio [3]. Even though this receiver is capable of receiving one high definition digital television service in real time, there is still place for some improvements which we are planning to do in the future. Such is the case of recovering the so-called Broadcast Transport Stream (BTS, for short), which will be explained in this article.

How this BTS must be recovered in reception is defined in the standard [4], but the explanation is not clear regarding the implementation. In [5] and [6, Sec. 7.3] there is some extra information, but how this should be implemented is still not fully explained. We found no other bibliography regarding this algorithm, but we knew that plenty of professional equipment implemented it. However, all of this equipment is closed and the processing blocks are no accessible. In order to implement it for *gr-isdbt*, we had to figure it out ourselves. We then compared our algorithm's outputs to the ones of some professional equipment and concluded they both matched perfectly.

The present article explains what is this BTS, why it is important for the receiver to recover it and, more importantly, a step by step explanation of how this must be performed. It even provides a pseudo-code explaining the algorithm, and an script implementing it may be downloaded from https://github.com/git-artes/gr-isdbt.

II. The ISDB-T Standard

ISDB-T stands for Integrated Services Digital Broadcasting - Terrestrial, and is the Japanese digital television standard. It is based on DVB-T, and was ratified in the early 2000's, after the European and the American standards were adopted. It was later adopted and adapted by Brazil: most importantly a new interactivity middleware named *Ginga* was defined (instead of the original *BML*) and MPEG-4 replaced MPEG-2 for source coding. The new version of the standard was named ISDB-Tb [7], and was later adopted by most South American countries.

Figure 1 shows the entire block diagram of the ISDB-T transmission system. Hereinafter we briefly discuss the specifications of each of the blocks, paying special attention to those aspects particular to ISDB-T. For more details, the interested reader should consult [4].

Let us begin by the *modulation scheme*. Orthogonal Frequency Division Multiplexing (OFDM) is used over a 6 MHz bandwidth channel. After the OFDM modulation, a cyclic prefix (CP) is added which length is expressed as a fraction of the active symbol's length, T_s. There are four possible values: $\frac{1}{4}, \frac{1}{8}, \frac{1}{16}$ or $\frac{1}{32}$. This CP is a copy of the last part of the OFDM symbol which is prepended to it. As we discuss in [2], it will be used in reception for symbol alignment and coarse frequency correction. Moreover, over multipath propagation channels, this prepending will eliminate inter-symbol interference and ease equalization (see for instance [8, Sec. 12.4]).

Regarding the number of carriers in one OFDM symbol, it can be either 2^{11}, 2^{12} or 2^{13} (fixed at a power of 2 so as to be able to use the FFT algorithm). However, the sampling rate (termed f_{IFFT} in the standard) is always equal to $512/63 \approx 8.126\,\text{MHz}$. This means that keeping the total data rate constant, the operator may choose to use more carriers but slower symbols in order to immunize the radio signal from multipath propagation effects, or less carriers but faster symbols in order to immunize the signal from Doppler effect. This choice is termed *Transmission Mode*, and may be either 1, 2 or 3, although generally mode 3 is used.

Focusing on mode 3 from now on, not all the 8192 carriers are used, but rather 5617, enough to meet the bit-rate and bandwidth requirements (where a guard interval and zero-padding is used in the rest of the carriers). This useful spectrum is in turn sub-divided into 13 sub-bands named *segments*, of 432 carriers each. These 13 segments may be used independently from one another, a feature first implemented in ISDB-T and called *Band-Segmented Transmission OFDM* (BST-OFDM). Particularly, they can be combined in up to three so-called *hierarchical layers* (A, B and C), which transmit different *MPEG Transport Streams* (TSs). Moreover, these groups of segments can be configured to use different forward error correction (FEC) rates, time interleaving lengths

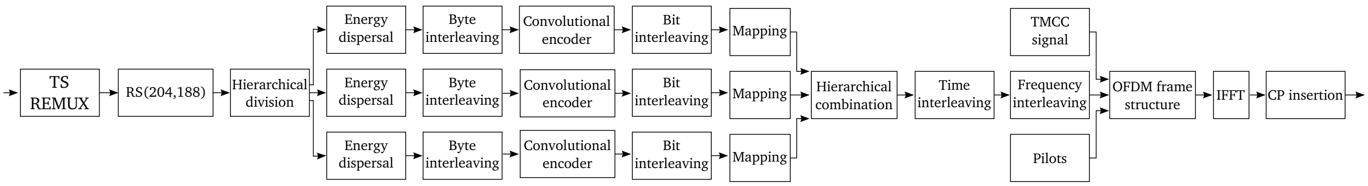

Fig. 1. ISDB-T transmission system block diagram.

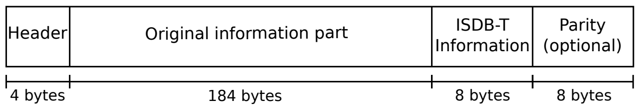

Fig. 2. TSPs that make up the BTS. The first 188 bytes correspond to the original TSP, while the last 16 bytes correspond to the ISDB-T Information and an optional parity check code.

and modulation schemes.

From the 5617 active carriers, there are several which are used as *pilots* to assist the receiver in the equalization process. These so-called *scattered pilots* (SP) change position from symbol to symbol to avoid pathological situations (such as a permanent deep fade in the spectrum), although their payload is known (which in turn depends on their position).

In addition to these pilots, several carriers are devoted to transmitting the modulation parameters at use. There are a total of 204 bits to be transmitted: the so-called *TMCC* (Transmission Multiplexing Configuration Control). They occupy fixed carriers in the OFDM symbol, each of them corresponding to the same TMCC's bit, and DBPSK modulation scheme is used. 204 OFDM symbols are thus required in order to receive the complete TMCC, completing a so-called *OFDM frame*.

The rest of the blocks are somewhat standard: frequency and a configurable time interleaving of the complex symbols; mapping, bit interleaving and convolutional encoder are applied to bits; byte interleaver, energy dispersal and Reed-Solomon encoding may be regarded as applied to bytes. It is important to highlight that most of these algorithms are applied separately to each layer (thus the three parallel paths in Fig. 1), and each layer may use its own set of parameters.

III. Transport Stream Re-multiplexing

As we mentioned in Section II, ISDB-T's BST-OFDM allows transmission in up to three independent hierarchical layers. Each layer is able to transmit one independent TS with its own channel coding and modulation scheme. Please note that **this functionality may need up to three independent inputs to the modulator**, i.e. one for each hierarchical layer. There is no way to input one single re-multiplexed TS, as the MPEG TS protocol does not provide any hierarchical information and there is no way to separate one TS from another, once all of them have been multiplexed together. In other words, the MPEG TS as it is cannot be applied to hierarchical transmission [5].

What ISDB-T did to solve this problem was to define the *Broadcast Transport Stream* (BTS), also known as *Transmission Transport Stream*. This BTS is created in the TS re-multiplexer (first block in Figure 1), combining up to three different TSs (one for each hierarchical layer). In this block, 16 extra bytes are added at the end of each TSP. These bytes are known as *dummy bytes* and are conformed as shown in Figure 2: the first 8 bytes are the *ISDB-T Information*, which indicates among other things, to which hierarchical layer the current TSP corresponds. The last 8 bytes are an optional Reed Solomon error correction code. The content of the ISDB-T Information can be consulted in [4] and it will not be discussed in this article. This BTS is the input to the modulator, which may be far away from the place where the BTS is generated (this is why there is an optional FEC in the dummy bytes). The transmission subsystem may even consist of more that one modulator, in different places far away from each other, for example for creating SFNs.

In addition to these new bytes of information, an extra packet is added to the BTS: the *ISDB-T Information Packet* (IIP, for short). This packet carries all of the transmitter configuration information; i.e. the number of hierarchical layers and for each of them the number of assigned segments, the corresponding FEC rate, time interleaving parameter and modulation scheme. All this information will then be sent to the receiver via the TMCC, which is created based on the IIP. This packet also carries out the information regarding the SFN synchronization, if any.

TABLE I
Number of TSPs per multiplex frame.

Transmission mode	Cyclic Prefix Duration (CP)			
	1/4	1/8	1/16	1/32
1	1280	1152	1088	1056
2	2560	2304	2176	2112
3	5120	4608	4352	4224

The BTS is made up in units of *Multiplex Frames*. These units are defined such that they carry out the same number of TSPs as one OFDM Frame. Each multiplex frame carries out only one IIP. Having stated the relationship between the multiplex frames and the OFDM frames, it is important to notice that for different configurations in the transmitter, different number of packets from up to three layers will compose a multiplex frame. Table I shows the number of TSPs in one multiplex frame (N_{mf}), for each possible combination of transmission mode and cyclic prefix. As it is shown in [5], the equation for calculating every value of the table is

$$N_{mf} = 2^{k-1}(1 + CP) \quad (1)$$

where k takes the values 11, 12 or 13 for transmission modes 1, 2 and 3 respectively, and CP is the cyclic prefix as a fraction of the active symbol's length. The same article also shows that in order to achieve perfect synchronization in all the transmitter chain, the BTS's bitrate must be exactly

$$r_{BTS} = 4 \times f_{IFFT} = \frac{2048}{63} \approx 32.508\, Mbps, \qquad (2)$$

where f_{IFFT} is the IFFT's sampling rate. In order to achieve this fixed bitrate for every possible configuration in the transmitter, null TSPs are added by the BTS re-multiplexer.

Finally, after the BTS arrives to the hierarchical divider, each TSP is routed to the corresponding layer. Each layer is then processed separately, modulated with its own modulation scheme and sent in parallel by using a multi-carrier OFDM signal. Thus, the information on the sequential order of the BTS gets lost in the serial-to-parallel process and the original BTS cannot be recovered in reception. But if the BTS changes its original order, **large *Program Clock Reference* (PCR) jitter may occur** [10], and this is inadmissible for video and audio decoding.

One way to solve this issue is to add some extra sequence information to each TSP in the multiplex frame. From Table I, one sees that the total number of TSPs included in one multiplex frame is at most 5120, which means that this method would require a minimum of 13 extra bits per TSP. To avoid adding extra information to each TSP, an algorithm for recovering the multiplex frame order in reception, just as it was arranged in the transmission side, was defined.

The arrangement by the transmitter must be such that if the receiver recovers the BTS with the defined algorithm, both TSPs sequences match perfectly. This arrangement was named *Multiplex Frame Pattern*, and it will be explained in the following section.

IV. The Multiplex Frame Pattern

The multiplex frame pattern must be recovered in reception based on the model receiver shown in Figure 3. If the multiplex frame is correctly arranged in the transmitter, the receiver will we able to recover it correctly.

After demodulation and time and frequency de-interleaving, the input to the hierarchical divider is a serial signal, with bits obtained from symbols in ascending order of segment number, and inside each segment, ascending order of carrier frequency. This serial signal is shown in Figure 4 for one OFDM frame (204 OFDM symbols). In this example, transmission mode 3 and a CP of $1/8$ were chosen. Each system clock corresponds to each FFT sample, or in other words, each carrier or *symbol*. The number of bits corresponding to each symbol depends on the modulation scheme chosen for the current hierarchical layer. It can be seen that in the end of each OFDM symbol some dummy data is added, which corresponds to the sum of discarded pilot and control carriers, FFT sampling excess (zero-padding in the FFT), and cyclic prefix sampling.

After this serial signal arrives in the *Hierarchical Divider*, it is depunctured based on the FEC rate set for each hierarchical layer, and the mother FEC rate, which is $fec_{mother} = 1/2$. Those bits are stored in the corresponding *Hierarchical Buffer* until the data reaches the size of one TSP. Being $mind_L$ and fec_L the modulation index and the FEC rate for the L_{th} hierarchical layer, respectively; the number of bits stored in the corresponding buffer in each system clock is

$$bitsperclock_L = \frac{mind_L \times fec_L}{fec_{mother}}. \qquad (3)$$

Please note that as the bits at this point have been depunctured, the corresponding number of bytes for one TSP is 408. In the precise moment when one *Hierarchical Buffer* reaches 408 bytes, the received TSP is moved to the *TSPs Buffer*. This is done by moving the switch S_1 to the correct *Hierarchical buffer*. Switch S_3 is used to select to which *TS Reproduction Unit* the TSP is delivered, but this will be explained later.

If we now concentrate on the last part of the model receiver, the expected bitrate at the output of the *Viterbi Decoder* must be the one defined for the BTS on Equation 2. This suggests that every some periodic time, the ideal receiver must output one TSP. In order to maintain a perfect synchronization between all the receiving chain, let us express the interval between two TSPs in system clocks, as we have expressed the input.

If we continue using the configuration of the example in Figure 4, based on Table I we can see that the number of TSPs in one multiplex frame is 4608. Also, the number of clocks in one multiplex frame can be obtained from Figure 4 by multiplying the clocks per OFDM symbol by the number of symbols in one OFDM frame, which by the way, agrees with one multiplex frame. If we now divide the number of clocks in a multiplex frame, by the number of TSPs in the frame, we get that the number of clocks per TSP is **exactly 408**. This means that every 408 system clocks, the model receiver must output one recovered TSP, and it can be seen that this is a constant value for every possible configuration. That TSP may be from layers A, B or C; depending on the order of arrival to the *TSPs Buffer*, or a Null TSP, if the buffer is empty.

So, every 408 clocks the *TS Reproduction Unit* must output one TSP. If there is one TSP in the *TSPs Buffer*, the *TS Reproduction* part switches S_2 and reads it out. Otherwise, S_2 is switched to the *Null TSP* position in order to read one Null TSP.

The switch S_3 is used to alternate the output of the *Hierarchical Combiner* between both *TS Reproduction Units* in order to start filling a new *TSPs Buffer* at the beginning of every OFDM frame. The moment in which S_3 is switched depends on the transmission mode:

- for **transmission mode 1** the switching is done at the beginning of every OFDM frame,
- for **transmission mode 2** the switching is performed twice in an OFDM frame (every 102 OFDM symbols) and
- for **transmission mode 3** the switching is performed four times per OFDM frame (every 51 OFDM symbols).

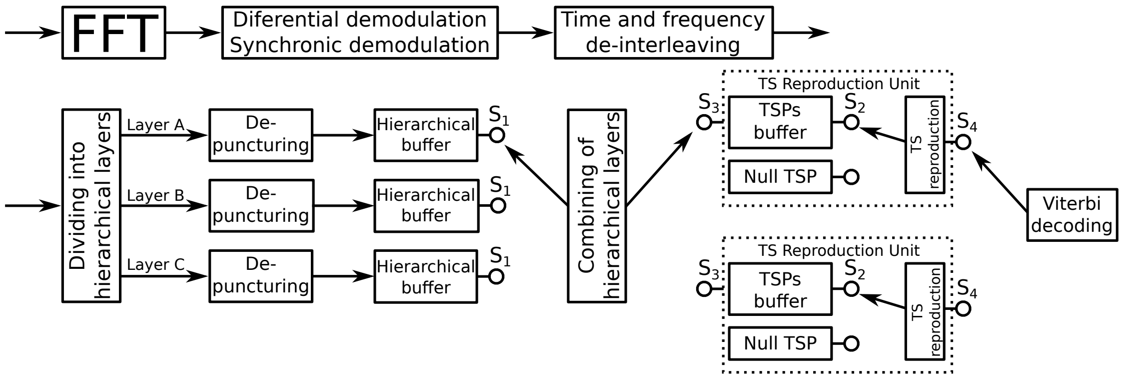

Fig. 3. Model receiver for recovering multiplex frame patterns.

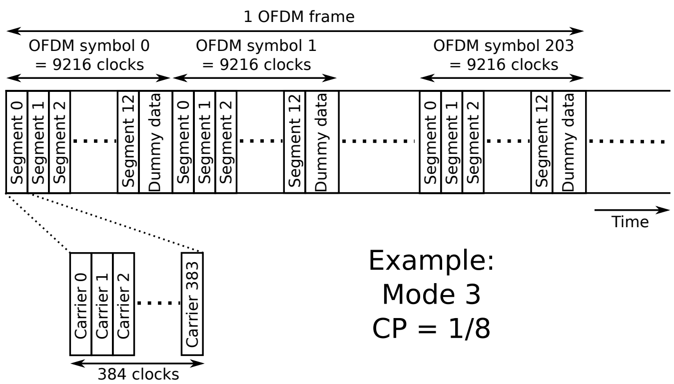

Fig. 4. Serial signal entering the hierarchical divider, for one OFDM frame.

Switch S_4 is used to switch between *TS Reproduction Section* outputs. Depending on the pattern of the input serial signal, i.e., the hierarchical configuration of the OFDM signal, TSP data might be left in the *TSPs buffer* at the end of an OFDM frame [5]. In order to output all the data within the OFDM frame duration, which is the same length as a multiplex frame, S_4 is switched to the same position as S_3 after 3 TSPs (408×3 clocks) following the switching of S_3.

The resulting algorithm for recovering the multiplex frame pattern is the one that follows:

$hbuffer_L \leftarrow 0$ {The *Hierarchical Buffer* for the L-th hierarchical layer is initialized as 0 bits}
$tsbuffer_N \leftarrow NULL$ {The *TSPs Buffers* are modeled as FIFO queues. Both ($N = \{1, 2\}$) are initialized as *NULL*}
while there is some input **do**
    for k=0:number of switches of S_3 per OFDM frame **do**
        for i=0: number of OFDM symbols per switch of S_3 **do**
            for j=0:system clock periods for one OFDM symbol **do**
                if (j $\in$ clock periods for *L*-th layer) **then**
                    $hbuffer_L \leftarrow hbuffer_L + \frac{mind_L \times fec_L}{fec_{mother}}$
                end if
                if $hbuffer_L \geq 408 \times 8$ **then**
                    $hbuffer_L \leftarrow hbuffer_L - 408 \times 8$
                    $tsbuffer_N \leftarrow TSP_L$
                end if
                if it is time to reproduce one TSP **then**
                    if there is at least one TSP in the *N'*-th *TSPs Buffer* **then**
                        read TSP from *N'*-th *TSP Buffer* {N' may differ from N depending on the position of S_4 and S_3 respectively}
                    else
                        reproduce *NULL* TSP
                    end if
                end if
            end for
        end for
    end for
end while

V. Conclusions

After our experience implementing *gr-isdbt* we were able to understand what is the BTS and why it was defined. We also understood why it is important for a receiver to recover it, and how this must be done exactly. As during this process we found the current bibliography is not clear regarding the implementation, we shared our experience in this article.

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