# ATSC Terrestrial Digital Television Broadcasting Using Single Frequency Networks

Yong-Tae Lee, Sung Ik Park, Seung Won Kim, Chieteuk Ahn, and Jong-Soo Seo

In this paper, we propose an efficient method to broadcast digital television signals using single frequency networks (SFNs) within the Advanced Television Systems Committee (ATSC) transmission systems. In implementing the SFNs of an 8-vestigial side band (8-VSB) Digital Television (DTV) system, the ambiguity problem of the trellis coder is unavoidable in a conventional ATSC transmission system. We propose a memory initialization of the trellis coder to resolve this ambiguity problem. Since the proposed scheme to synchronize multiple transmitters minimizes the changes from the conventional ATSC system, the hardware complexity for these changes is very low. Our simulation results show that the proposed scheme makes a less than 0.1 dB degradation at the threshold of visibility with a bit error rate of $3 \times 10^{-6}$ in the additive white Gaussian noise (AWGN) channel. It is possible to reduce the performance degradation by increasing the initialization period of the proposed scheme.

Keywords: DTV, SFN, ATSC.

## I. Introduction

In the terrestrial digital television (DTV) standard of the Advanced Television Systems Committee (ATSC), 8-vestigial side band (8-VSB) modulation was adopted as a modulation standard in the United States in December 1996 [1], [2]. On the other hand, the coded orthogonal frequency division multiplexing (COFDM) modulation was chosen as the European and Japanese DTV standards known as Digital Video Broadcasting-Terrestrial (DVB-T) and Integrated Serviced Digital Broadcasting-Terrestrial (ISDB-T) [3], [4].

The standard of each of these systems has its own unique advantages and disadvantages [5]-[7]. The ATSC system is more robust in an additive white Gaussian noise (AWGN) channel, has a higher spectrum efficiency, a lower peak-to-average power ratio, and is more robust against impulse noise. It also has a performance comparable with DVB-T and ISDB-T systems on low-level ghost ensembles and is more robust against analog TV interference. Therefore, the ATSC system might be more advantageous for multi-frequency network (MFN) implementation as well as for providing high-definition television (HDTV) service within 6MHz channels on fixed receivers.

The DVB-T system has performance advantages with respect to high-level (up to 0 dB), long-delay, static and dynamic multi-path distortions. This system may be advantageous for services requiring large-scale single frequency networks (SFNs) (8k mode) and for mobile receptions (2k mode).

Since the ISDB-T system uses the same modulation and channel coding schemes as the DVB-T system, it has similar performance advantages as the DVB-T system. It is also designed to operate under large-scale SFNs and, particularly, in a mobile reception environment.

However, it should be pointed out that large scale SFNs, mobile reception, and HDTV service cannot be achieved concurrently without severe data rate or carrier-to-noise ratio penalties for all existing DTV systems over any channel spacing of 6, 7, or 8 MHz. Specific system parameters should be selected for particular implementations.

In Korea, the Terrestrial Digital Broadcasting Committee, including broadcasters, industries, and research institutes, was organized in 1997. The Committee not only analyzed the terrestrial DTV standards but also recommended the best one for implementation in Korea to the Ministry of Information and Communication. As a result of their careful consideration, the Ministry of Information and Communication selected the ATSC standard as the Korean DTV standard in 1997. Following field tests in 1999 and trial broadcasting in 2000, commercial broadcasting was initiated in the Metropolitan Seoul area in October 2001. Currently, all 5 major stations (KBS1, KBS2, SBS, MBC and EBS) have commenced HDTV broadcasting service in the Seoul area using three transmitters. By 2004, HDTV will be provided in major metropolitan areas, and by 2005, a nationwide HDTV service will be available. In 2002, FIFA World Cup soccer matches and the Busan Asian Games were successfully broadcasted using the HDTV format. HDTV is one of the most important applications of the terrestrial DTV service in Korea.

The DTV broadcasting service currently employs the MFN. For example, the Munhwa Broadcasting Corporation (MBC), which is one of the public broadcasters in Korea, transmits its DTV signal on CH 14 from a Gwanak Mountain site, on CH 61 from a Nam Mountain site, and on CH 60 from a Yongmoon Mountain site to cover the Seoul area. The MFN is a simple and realistic way to allocate the transmission channels during a transition period to DTV. However, the spectral efficiency is not high, even if the channel spectrum can be reused in distant areas.

On the other hand, some nations use the COFDM modulation scheme to broadcast from a group of transmitters operating at a common frequency recognized by the SFN. The most important aspect of the SFN is its spectral efficiency. Also, the SFN enables an effective mobile DTV service.

The ATSC system has not been specifically designed for SFN implementation. A limited on-channel repeater and gap filler operation is possible, if enough isolation between the pick-up of the off-air signal and its retransmission is provided. Recently, there are some trials being conducted to implement the SFN with multiple transmitters in the ATSC system [8], [9]. Furthermore, as a result of the various efforts to enhance the performance of the ATSC system, an ATSC receiver can handle high-level (up to 0dB), long-delay, static and dynamic multi-path distortions [10]. In particular, a report from the

Communication Research Centre (CRC) Canada shows that a consumer ATSC receiver has a similar or superior performance in the multi-path distortion channel compared to a DVB-T receiver [11]. Therefore, it would be possible to employ SFNs in the ATSC system.

In this paper, we briefly present the requirements and problems for transceivers in implementing an SFN in the ATSC system [8], [12]. Also, we analyze the ambiguity problem of this trellis coder and propose an effective method to resolve this ambiguity. Our simulation shows that the proposed method results in a maximum 0.1 dB degradation at the threshold of visibility (TOV) with a bit error rate of $3\times10^{-6}$ in the AWGN channel. This performance degradation can be further reduced by increasing the initialization period of the trellis coder.

This paper is organized as follows. Section II describes the ATSC DTV system. In section III, we describe requirements to implement an SFN in an ATSC system. In section IV, the implementation of an SFN in a DVB-T system is investigated. To overcome the ambiguity problem of the trellis coder, the modified pre-coder and trellis encoder are proposed in section V. In section VI, simulation results on the proposed trellis coder are presented. Finally, section VII concludes this paper.

## II. ATSC DTV System

A basic block diagram of the ATSC DTV broadcasting system is shown in Fig. 1. It consists of the following subsystems: data compression, service multiplex and transport, 8-VSB transmission, and an 8-VSB receiver.

Data compression refers to the bit-rate reduction methods appropriate for application to video, audio, and ancillary digital-data streams. Ancillary data includes control data, conditional-access control data, and data associated with the program audio and video services, such as closed captioning. The ATSC DTV system employs MPEG-2 video-stream syntax for video coding and the digital audio compression (AC-3) standard for audio coding.

Service multiplex and transport refers to the means of dividing the digital data stream into packets of information, the means of uniquely identifying each packet, and the appropriate
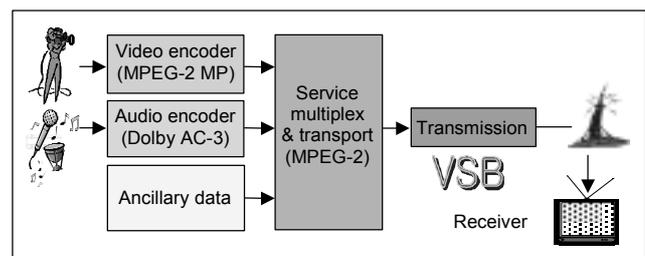


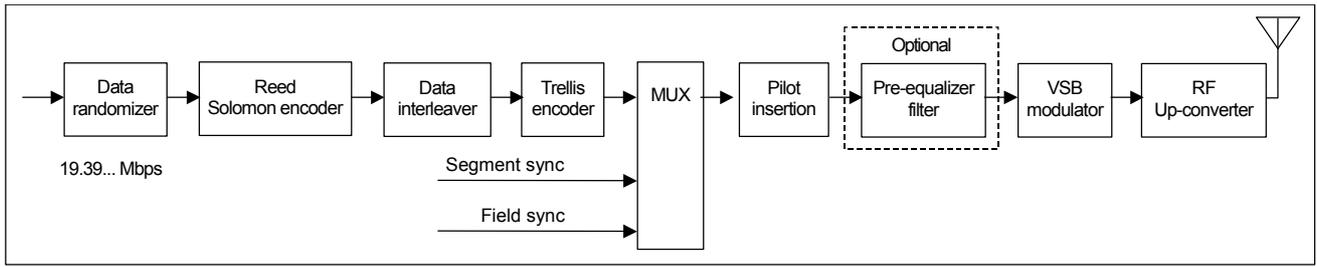Fig. 1. ATSC DTV broadcasting system.
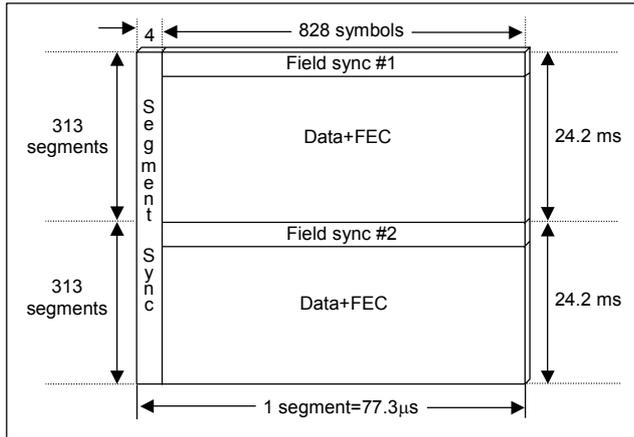
Fig. 2. 8-VSB transmitter block diagram.



Fig. 3. Structure of VSB DTV data frame.

methods of multiplexing the video data-stream packets, audio data-stream packets, and ancillary data-stream packets into a single data stream. For the packetization and multiplexing of video, audio, and ancillary data, the ATSC DTV system employs the MPEG-2 transport stream (TS) syntax. It was developed for applications where channel bandwidth or recording media capacity is limited and the requirement for an efficient transport mechanism is paramount.

Transmission refers to channel coding and modulation. The channel encoder takes the bit-stream data and adds additional information that can be used by the receiver to reconstruct the data from the received signal, which may not accurately represent the transmitted signal due to transmission impairments. The modulation uses the digital data-stream information to modulate the transmitted carrier with a VSB filter. Since VSB modulation

has an asymmetrical property, a VSB modulated signal includes quadrature components as well as an in-phase components [12].

Figure 2 shows a functional block diagram of an 8-VSB transmitter. The input to the transmission subsystem from the transport subsystem is a 19.39 Mbps serial data-stream comprised of 188-byte MPEG-compatible data packets. The incoming data is randomized and then processed for forward error correction (FEC) in the form of Reed-Solomon (RS) encoding (20 RS parity bytes are added to each packet), 1/6 data field interleaving, and 2/3-rate trellis coding. Randomization and FEC processes are not applied to the sync byte of the transport packet, which is represented by a data segment sync signal. Following randomization and FEC processing, the data packets are formatted into data frames for transmission, and a data segment sync and data field sync are added.

Figure 3 shows how the data in an 8-VSB DTV system are organized for transmission. Each data frame consists of two data fields, each containing 313 data segments. The first data segment of each data field is a unique synchronizing signal (data field sync) and includes the training sequence used by the equalizer in the receiver. The remaining 312 data segments each carry the equivalent of the data from an 188-byte transport packet plus its associated FEC overhead. The actual data in each data segment comes from several transport packets due to data interleaving. Each data segment consists of 832 symbols. The first four symbols are transmitted in binary form and provide data segment synchronization. This data segment sync signal also represents the sync byte of the 188-byte MPEG-compatible transport packet. The remaining 828 symbols of each data segment carry data equivalent to the remaining 187
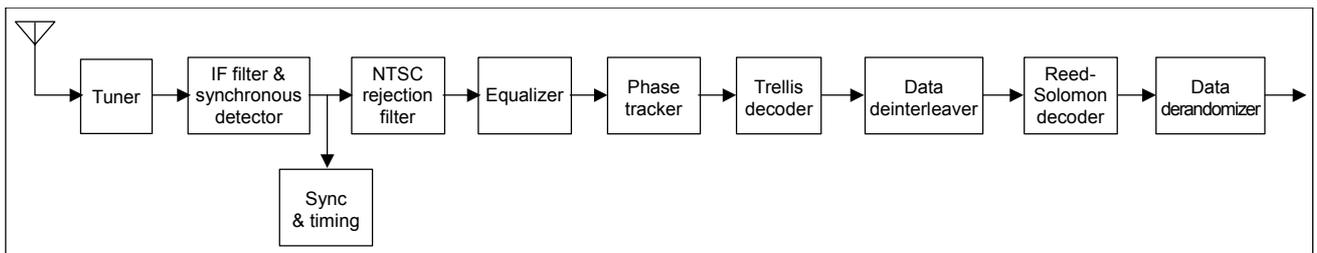


Fig. 4. 8-VSB receiver block diagram.

bytes of a transport packet and its associated FEC overhead. These 828 symbols are transmitted by 8-level signals which carry three bits per symbol.

The receiver block diagram of the 8-VSB DTV system is shown in Fig. 4. The receiver architecture and choice of algorithms for synchronization and equalization are not mandated by the standard.

## III. Requirements to Implement SFN in an ATSC System

The SFN consists of multiple transmitters all sharing a single channel. The transmitters must emit identical signals, several of which may be received more or less simultaneously by individual receivers. The receivers must treat the multiple received signals as echoes of one another, and extract the transmitted data despite possible interference from alternate transmitters within the SFN. The following subsections describe the requirements and problems in implementing an SFN in the ATSC DTV system.

### 1. SFN at the Transmitter Side

There are three fundamental requirements for transmitters in an SFN: i) They must transmit on the same frequency, ii) they must transmit their signals in specific time slots, and iii) they must emit the same output symbols for the same data inputs.

#### A. Frequency Synchronization

If the signals arriving at a receiver from multiple transmitters are to be treated as echoes of one another, the frequencies of those transmitters must be close enough to each other. Any divergence in frequency will cause the apparent echoes to have the characteristics of a Doppler shift. Such Doppler shifts place additional burdens on adaptive equalizers in receivers.

The above requirement can be resolved by using an external common 10 MHz frequency reference from a global positioning system (GPS), as shown in [13].

#### B. Emission Timing Synchronization

In order to enable multiple transmitters in an SFN to be set to transmit their signals in specific time slots, it is necessary to provide a time reference to all of the transmitters.

For the emission-timing synchronization, MPEG-2 TS packets distributed by a studio to multiple transmitters should contain a special packet which can control the emission time. The DVB-T system inserts a special packet called a mega-frame initialization packet (MIP) in the MPEG-2 TS [13]. In the ATSC system, there is no standard for the emission timing

synchronization, however the ATSC T3S9 Ad Hoc Group on distributed transmission recently proposed the Distributed Transmission Packet as the corresponding special packet [8].

#### C. Data Frame and Trellis Coder Synchronization

To achieve synchronization between the output symbols of transmitters having separate data feeds as inputs, it is necessary to synchronize the data processing blocks consisting of data randomizers, RS encoders, byte interleavers, bit interleavers, and the trellis encoder. Any divergence of the output symbols between transmitters will make the receivers unable to treat the signals as echoes of one another.

▫ Data Frame Synchronization

To synchronize the data processing blocks consisting of data randomizers, RS encoders, byte interleavers, and bit interleavers, it is necessary to know the starting point of the data field, since the blocks are synchronized by this starting point.

If there is an index signal indicating a starting point in the MPEG-2 TS packets distributed by a studio to multiple transmitters, we can synchronize the data processing blocks of the multiple transmitters. The data field segment inserted by the modulator must also be synchronized. This creates a data frame structure composed of two data fields as shown in section II. Because of the integer phase relationship between the data frame and its two data fields, it is possible to synchronize the data frame structure and derive the data fields from it.

▫ Pre-Coder and Trellis Encoder Synchronization

The inputs to the pre-coder and trellis coder are random data, and there is no control for the status of the pre-coder and trellis coder in the ATSC standard. A different initial status will result in a different encoder output, even if the input to the encoder is the same. This phenomenon is called a "trellis coder ambiguity of the ATSC system." Thus, it is necessary to develop a specific state condition for remembering the pre-coder and trellis encoder at a specific instant.

### 2. SFN at the Receiver Side

The implementation of SFNs depends very much on the ability of receivers to extract data from the received signals having significant levels of echoes at widely-spaced time offsets. This capability includes the handling of leading echoes, or "pre-ghosts," that result from stronger signals arriving at a receiver from transmitters that are further away or have delayed emission times relative to a nearer transmitter. The time window of echoes, i.e., the "delay spread," that can be handled by receivers partly determines how far apart transmitters can be placed in the SFN.

As a result of various efforts to enhance the performance of the ATSC system, the ATSC receiver can handle high-level (up to 0 dB), long-delay, static and dynamic, multi-path distortions [10]. In particular, a report from CRC shows that a consumer ATSC receiver has the same or superior performance in the multi-path distortion channel as a DVB-T receiver [11]. Therefore, it would be possible to employ SFNs in an ATSC system.

## IV. SFN in DVB-T System

In this section, we briefly describe a complete SFN in a DVB-T system. Figure 5 shows a block diagram of an SFN system. The SFN functionality is an extension to the DVB-T system. The blocks associated with SFN functionality are shown as gray boxes in Fig. 5.

In a DVB-T system, the SFN adapter and synchronization (SYNC) system are included for transmitter synchronization. The SFN adapter forms a mega-frame that consists of $n$ TS-packets corresponding to DVB-T frames and inserts an MIP with a dedicated Packet Identifier value. Inserted MIP identifies the starting point of the next mega-frame. The SYNC system will provide a propagation time compensation by comparing the synchronization time stamp with the local time reference, such as 1 pulse per second (PPS) from a GPS, and calculating the extra delay needed for SFN synchronization. For more details refer to [13].

Transmitter/Receiver network adapters provide a transparent link for the MPEG-2 TS packets from the central (ex. studio) to local units (ex. transmitters). The maximum network delay is caused by the different paths of the transmission networks, such as fibers, satellites or microwaves.

The added blocks for the SFN in a DVB-T system can be applied to the ATSC system with some changes for transmitter synchronization.

## V. Proposed SFN in an ATSC System

Figure 6 shows the proposed configurations of the ATSC system for an SFN. In the figure, the gray blocks represent the blocks associated with SFN functionality. For data-frame synchronization, we employ the starting-index inserter block at the studio and starting-index detector block at each transmitter. Also, for pre-coder and trellis encoder initialization, we change the conventional trellis coder scheme into the proposed scheme at each transmitter.

We assume two things to satisfy the requirements. The first is that the arriving time of an MPEG-2 TS packet from a studio to each transmitter is the same. The second is that the transmitter is synchronized by the external frequency reference. These assumptions can be implemented by modifying the SFN adapter and SYNC system blocks of the DVB-T SFN or using the synchronization method proposed by the ATSC T3S9 Ad Hoc Group on distributed transmission [8], [13].

In this section, we propose efficient synchronization methods for the data frame and trellis coder consisting of a pre-coder and trellis encoder. Since the proposed schemes minimize the changes from the conventional ATSC system, the hardware complexity for the changes is very low.

### 1. Data Frame Synchronization

In a conventional ATSC system, the MPEG-2 TS packet consists of a sync byte with 0x47 and 187 bytes of data payloads.

Since there is no index indicating a starting point, it is impossible to identify the starting point of the distributed MPEG-2 TS packets.

When a method is created to properly identify a starting point for the data field, it will be easy to synchronize the data randomizer, RS encoders, byte interleavers, and bit interleavers of the multiple transmitters.
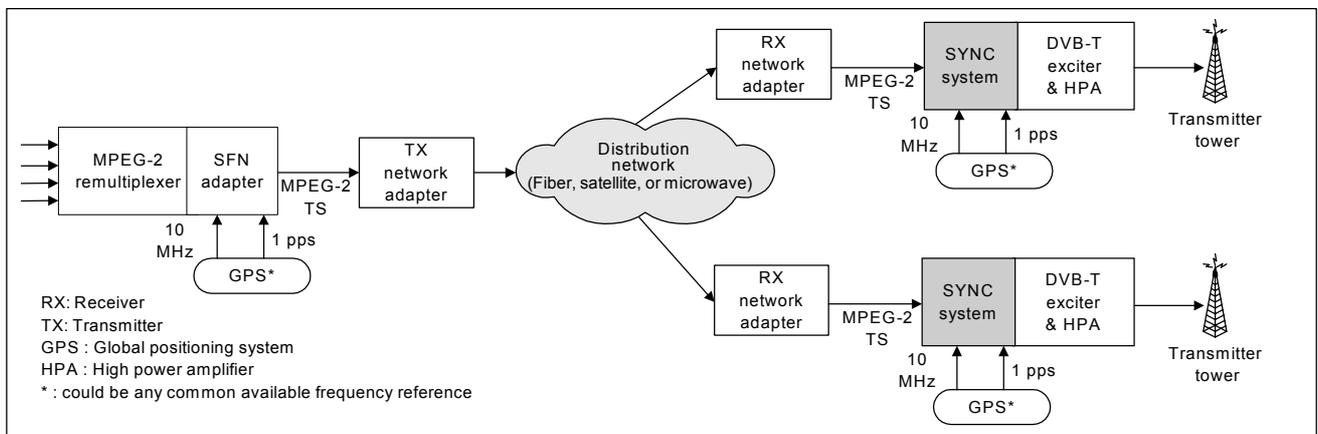


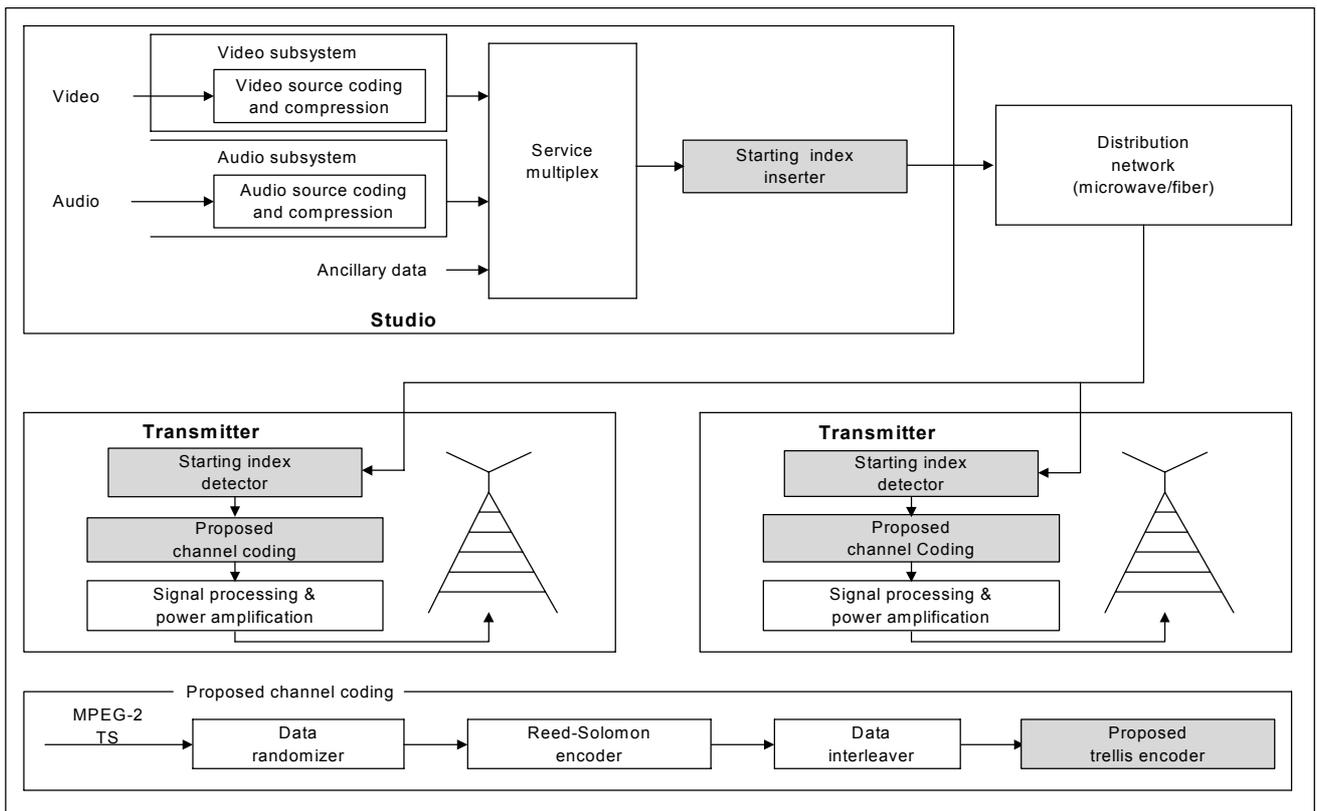Fig. 5. DVB-T primary distribution with SFN adaptation.

Fig. 6. The proposed configurations of ATSC system for SFN.

For easy of data-frame synchronization, we set a starting-index inserter at the studio and starting-index detectors at the multiple transmitters, as shown in Fig. 6. The starting-index inserter replaces the header of the MPEG-2 packet with 0xB8 per every $N(\geq 1)$ data frame containing 624 MPEG-2 packets. The 0xB8 is a bit-wise inverse of the normal MPEG-2 TS packet header used as a Cadence sync word proposed by the Merrill Weiss Group [8]. The starting-index detector first searches for an MPEG-2 packet having a 0xB8 as a sync byte using a correlation process, and then changes the 0xB8 into an original sync byte, 0x47.

By identifying a starting point of a data frame through the index signal, we can easily synchronize the data processing blocks consisting of data randomizers, RS encoders, byte interleavers, and bit-interleavers of the multiple transmitters.

## 2. Proposed Pre-coder and Trellis Encoder

### A. Ambiguity of Pre-coder and Trellis Encoder in an ATSC System

Figure 7 shows the structure of a trellis coder that consists of a pre-coder, trellis encoder, and 8-level symbol mapper. The trellis encoder is used to extend the reception threshold of the receiver by permitting the use of soft-decision Viterbi decoding
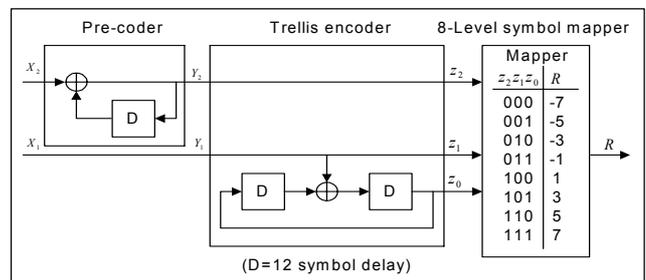


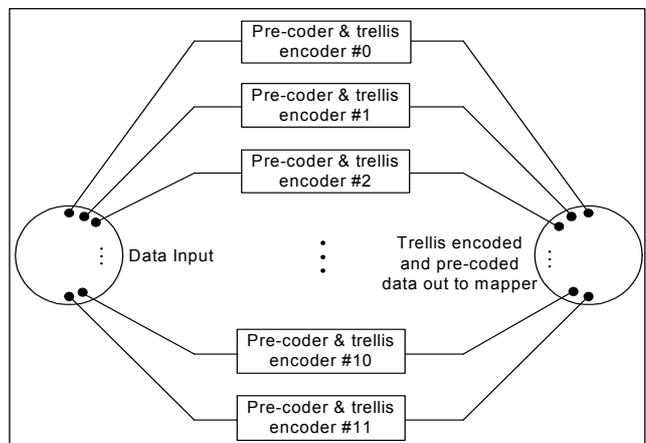Fig. 7. The conventional trellis coder of ATSC system.



Fig. 8. 12 interleaved trellis coders of ATSC system.

Yong-Tae Lee et al.   **97**

[14], [15]. The pre-coder is used to compensate for the comb filters of the receivers to reduce co-channel interference of the NTSC signals. Also, in order to protect the trellis encoder against short burst errors, such as an impulse noise or NTSC co-channel interference, twelve interleaved trellis coders are used, as shown in Fig. 8.

The pre-coder uses an accumulator structure with 1-bit memory and the trellis encoder uses a convolutional code with 2-bit memory. The states of these memories at any given instant are dependent on the data presented prior to that instant, with no initialization done at any time. Thus, it is impossible to synchronize the pre-coder and trellis encoder by identifying any element of the data signal fed to the transmitter.

As a result of no initialization of the pre-coder and trellis encoder, the emitted symbols of the multiple transmitters are not the same even though the input signal of the transmitters is the same. This will make the receivers unable to treat the several signals as echoes of one another.

### B. Proposed Initialization Method of the Pre-coder and Trellis Encoder in an ATSC System

In this subsection, we propose a modified pre-coder and trellis encoder to resolve the ambiguity problem. The basic structures of the proposed pre-coder and trellis encoder are the same as the conventional structures of the ATSC system except for the switching of circuits for initialization of the memories. Figure 9 shows a structure of the proposed pre-coder and trellis encoder. In fact, twelve identical proposed trellis coders are used for the trellis code interleaver.

For the initialization of the pre-coder memory, the switching circuit connects the initialization path, $S_2$, instead of $X_2$, and for the initialization of the trellis encoder memories, the switching circuit connects the initialization path, $S_1$, instead of $Y_1$. The initialization processes occur per every $M(\geq 1)$ data fields during the last 48 bits of the $(312 \times M)$-th data segment. Then, the memories of the pre-coder and trellis encoder are initialized to 0 and 00 states, respectively.

For the initialization of one pre-coder and trellis encoder, at least four bits are required. However, since twelve interleaved
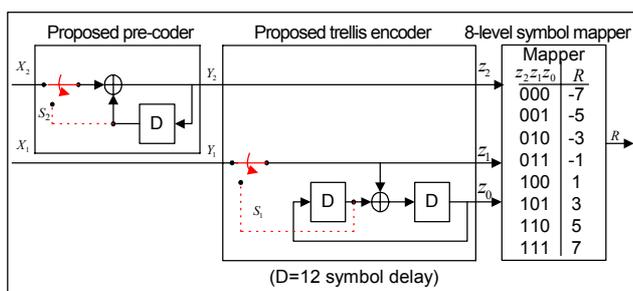


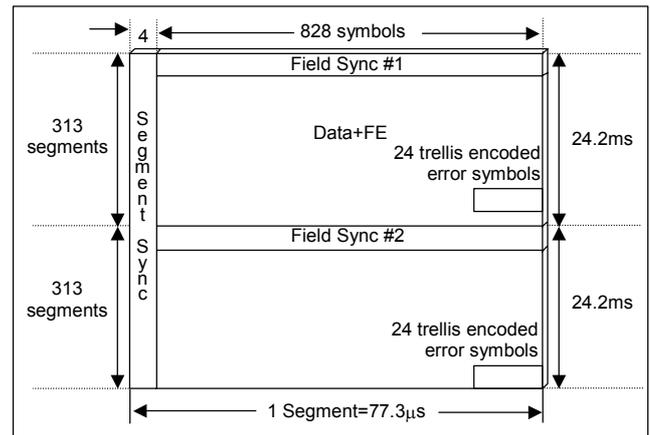Fig. 9. Proposed trellis coder of ATSC system.



Fig. 10. VSB data frame initialized per every one data field.

trellis coders are used in an ATSC system, a total of 48 bits are required to initialize the memories. These 48 bits generate 24 trellis-encoded error symbols for initialization. Figure 10 shows a VSB data frame initialized per every one data field.

As a result of the initialization of the memories in the trellis coders, the trellis coder ambiguity disappears. Then, multiple transmitters have the same output symbols for the same data input. The output signals can be treated as echoes of one another. However, the initialization processes make 24 trellis-encoded error symbols per every $M$ data fields. These symbol errors can be corrected by using FEC codes such as a Viterbi decoder and RS decoder in the receiver. Furthermore, it is possible to make the effect of the error symbols ignorable by increasing the initialization period, $M$.

## VI. Simulation Results

In this section, computer simulations are performed to demonstrate the output symbol patterns of the proposed trellis coder and the performance of the proposed trellis coder in an additive white Gaussian noise AWGN channel.

### 1. Output Symbol Patterns of the Original and Proposed Trellis Coder

In the simulation, we assume that each transmitter has an identical data input and the initialization process is performed in every data field. Also, two transmitters are assumed to generate four data fields. For easy viewing, we observe the first 75 symbols in each data field. Figure 11 shows that output symbols of two transmitters are different for their corresponding transmitter inputs if the initialization process is not performed. Figure 12 shows that two transmitters with the proposed pre-coder and trellis encoder have the same output symbols for their identical corresponding transmitter inputs. In

Figs. 11 (a) and 12 (a), the initial states of twelve trellis encoders are all 0 (00), and in Figs. 11 (b) and 12 (b), the initial states are all 3 (11). The X–axes in Figs. 11 and 12 show the value of the trellis coder's output symbols. Y-axes in Figs.11 and 12 show the number of symbols.

Our simulation results show that the initialization of the pre-coder and trellis encoder results in the same output symbols for the same input data.
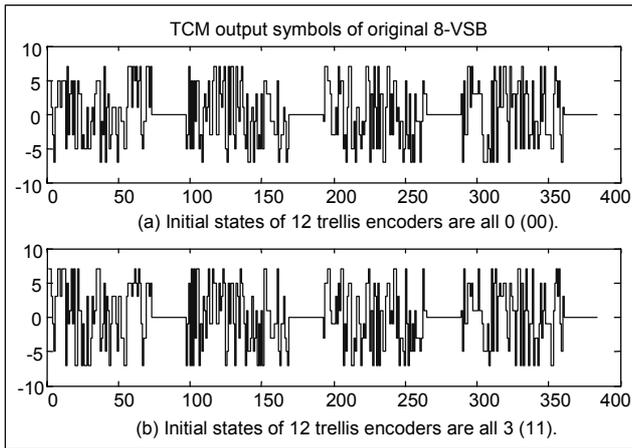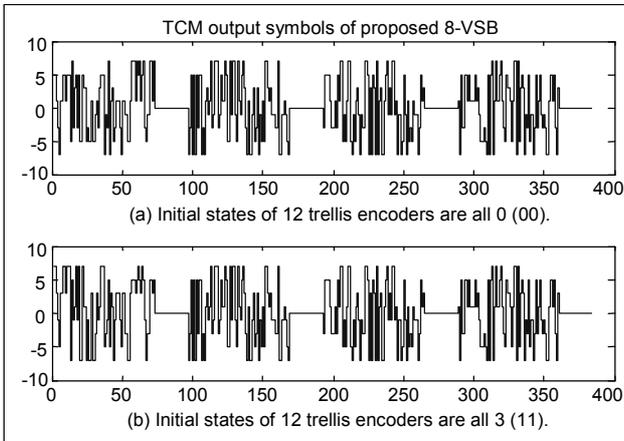


Fig. 11. Output symbols of the original trellis coder.



Fig. 12. Output symbols of the proposed trellis coder.

## 2. Performance of Original and Proposed Trellis Coders

Figure 13 shows the performance of an 8-VSB signal encoded by the original and proposed trellis coders in an AWGN channel. The X-axis in Fig.13 shows a bit and segment error rate of a received signal. The Y-axis in Fig.13 shows the signal-to-noise ratio of a received signal. In the simulation, the initialization process is performed for every data field. The result shows that the performance of an 8-VSB system employing an original trellis coder is about 0.1 dB better than the proposed trellis coder at the threshold of visibility. The

reason for the performance degradation is that 24 trellis-encoded error symbols reduce the error-correcting capability of the RS code in three of 312 RS packets in each data field. As long as the total number of errors caused by the channel and 24 trellis-encoded error symbols are within the error-correcting capability of the RS code, the existing receivers can correct the 24 error symbols caused by the proposed trellis coder. Furthermore, it is possible to reduce the performance degradation by increasing the initialization period, $M$, of the trellis coder.
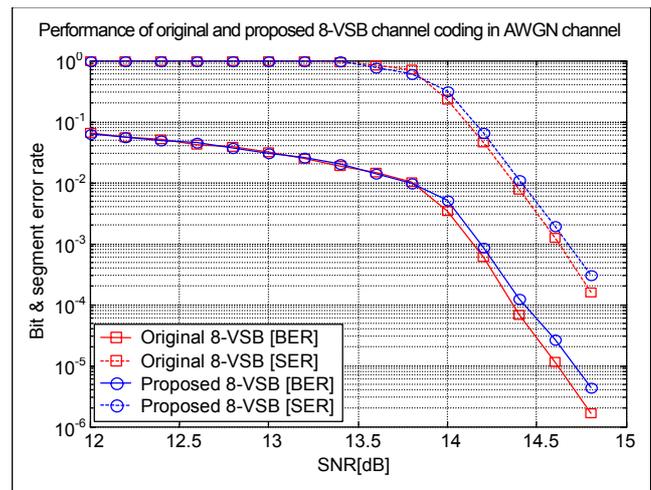


Fig. 13. The performance of 8-VSB signal encoded by original and proposed trellis coder.

## VII. Conclusions

To implement single frequency networks of an 8-VSB DTV system, the ambiguity problem of a trellis coder is unavoidable in a conventional ATSC transmission system. In this paper we have proposed a memory initialization of a trellis coder to resolve the ambiguity problem. The proposed schemes used to synchronize the multiple transmitters minimize the changes from the conventional ATSC system. Therefore, the increase in hardware complexity due to the changes is very low. We have found that the proposed scheme makes less than a 0.1 dB degradation at the threshold of visibility in the AWGN channel. It is possible to reduce the performance degradation by increasing an initialization period of the proposed trellis coder. The proposed trellis coder scheme presented in this paper may be very useful for developing SFNs in an ATSC system.

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