

Distributed Translator Systems for ATSC

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Abstract

Distributed transmission is single frequency network technology applied to the ATSC system for digital television. Rather than using a single transmitter to service a coverage area, multiple transmitters are used. The transmitters are synchronized in frequency and symbol emission. The ATSC Distributed Transmission was originally developed with the intention of supplying a studio to transmitter (STL) link to every distributed transmitter.

Translator systems, however, receive their signals off the air and retransmit on another channel. During the analog to digital transition, there may not be enough channels available to build full translator networks for both signal formats using conventional translators. But distributed transmission allows all of the translators to use as little as just one additional channel.

One essential function of the distributed transmission system is to communicate trellis code synchronization information to distributed transmitters via a dedicated packet. The packet, part of the ATSC payload, is normally sent over STL systems. However, because of causality constraints, the trellis code data must be removed from the packet before the packet goes on the air. This means that the synchronization data necessary to operate a distributed transmission network is normally lost in the off-air signal.

This paper describes methods of operating single-hop and multiple-hop distributed translator networks with only minor changes to the CS/110A candidate standard for distributed transmission. With this technology, distributed translators become possible and there is no need for an STL to every transmitter site.

Introduction

In some areas, particularly in the west, there are many translators on the air. However, even in relatively unpopulated areas, there simply are not enough channels available to provide DTV translator service at the same level where NTSC translator service already exists.

In a traditional translator system, many channels may be used in addition to the originating channel. A more efficient use of spectrum would be to use just *one* additional channel for the translators, by applying distributed transmission technology.

The distributed transmission system is based on the use of STLs to transmit the modified SMPTE 310 data to *all* of the transmitters in a network. This is acceptable and even desirable for many applications. But translator systems are intended to receive signals off the air, and to retransmit them on another channel. Requiring translators to have STL systems would seem redundant – why require the same signal to be delivered to a translator site *twice*?

Operators of translator systems would like to be able to take a signal off the air, and use that signal to drive a network of synchronous distributed translators.

As originally conceived, the distributed transmission system did not support off-air operation. However, some new ideas have been developed which can make distributed translators possible. These new concepts are discussed in this paper. These methods will require some slight modifications to the ATSC candidate standard.

Brief Review of Distributed Transmission

In a Distributed Transmission (DTx) system, all of the transmitters in a network are synchronized in frequency, data, and timing.

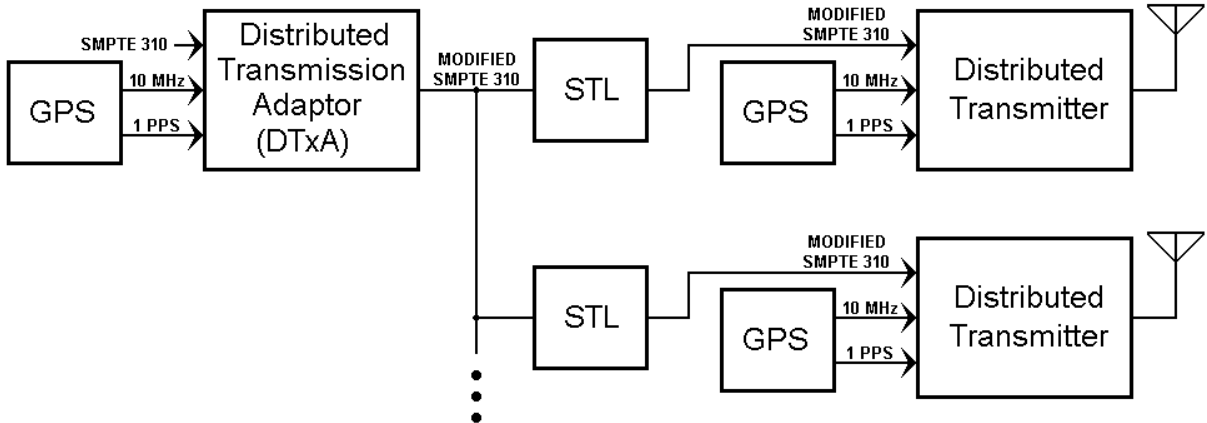


Figure 1 – Distributed Transmission (DTx) System

Figure 1 shows a DTx system. A Distributed Transmission Adaptor (DTxA) inserts network control data into the SMPTE 310 stream. Frequency synchronization is achieved by locking the transmitter’s pilot to a 10 MHz GPS reference. Timing synchronization is also referred to GPS.

Data synchronization is necessary because of the nondeterministic nature of ATSC modulators. The trellis coders and precoders present in an ATSC modulator start up with arbitrary initial conditions. There are 36 bits in the trellis coders and precoders. In addition, an ATSC modulator makes an arbitrary choice of where to inject frame sync (once every 624 MPEG packets). This results in $624 * 2^{36} = 42,880,953,483,264$ different ways to transmit the same signal. So without a synchronization method, two ATSC modulators fed with the same signal would have about one chance in 43 trillion of producing the same symbol sequence.

(From this point on in this paper, the nomenclature convention established in ATSC documents and other engineering papers will be adopted; the trellis coder and precoder states will be referred to as simply “trellis coder states,” with the precoder states being implicitly included.)

So, a distributed transmission system must have a way to synchronize the arbitrary initial conditions so that all transmitters are generating the same symbol sequence. This is accomplished by modeling the channel coding process in the DTxA, and by sending the formerly arbitrary state information to all of the slave transmitters in the network in a Distributed Transmission Packet or DTxP.

The DTxP also carries data that tells each transmitter where to set its timing. The timing reference is a one pulse per second (1 PPS) clock signal derived from a Global Positioning System (GPS) receiver. Timing of each transmitter may be slightly advanced or delayed to optimize reception in populated overlap areas.

In a conventional distributed transmission system, the DTxA modifies the SMPTE 310 input signal by inserting the distributed transmission packet, cadence sync, and the field rate side channel. The resulting SMPTE 310 signal is then sent to all transmitter sites in a network via Studio to Transmitter Link (STL) systems – which may include microwave, fiber, satellite, or other means.

Review of Conventional Translators

A conventional translator receives an analog or digital television signal on one channel and retransmits on a second channel. Where multiple translators are used, they often use different channels from one another to avoid mutual interference. This is inefficient use of spectrum.

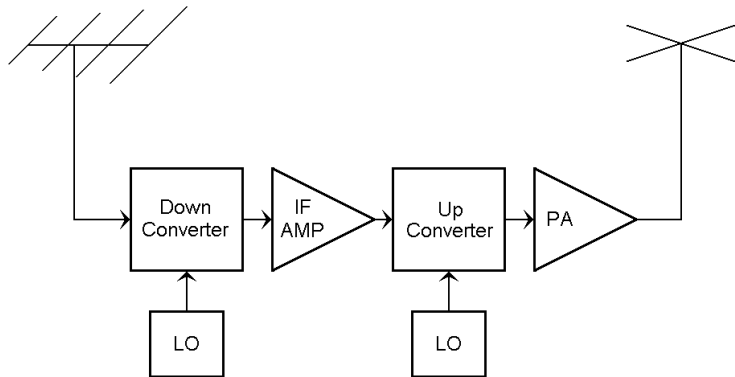


Figure 2 – Conventional Translator

Figure 2 shows a conventional translator, usable for either analog or digital signals. An off air signal is shifted by a local oscillator (LO) to an intermediate frequency (IF) where it is filtered and amplified. The signal is up converted to a different channel, amplified, and retransmitted.

Review of On-Channel Repeaters (OCRs)

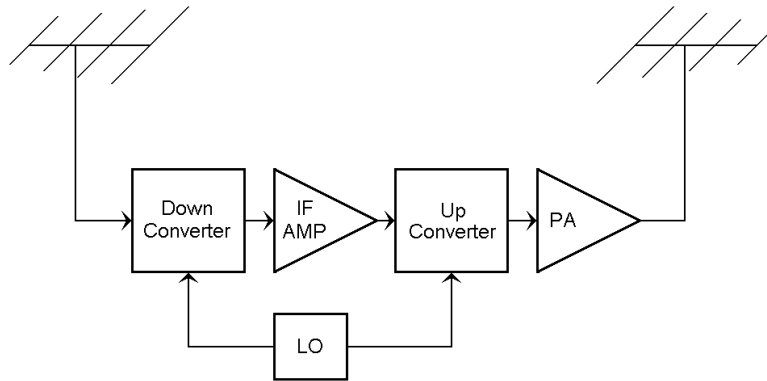
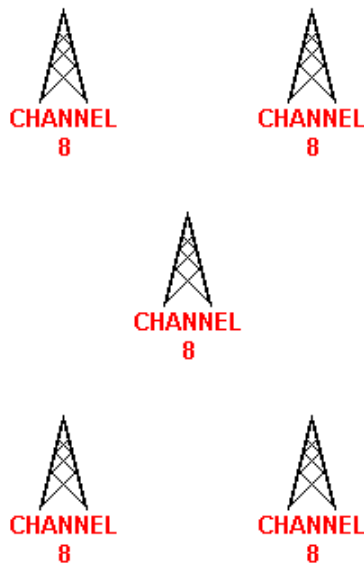


Figure 3 – On-Channel Repeater (OCR)

down conversion and up conversion, resulting in a coherent output signal on the same channel as the input signal. A high degree of isolation is required between the receive and transmit antennas.

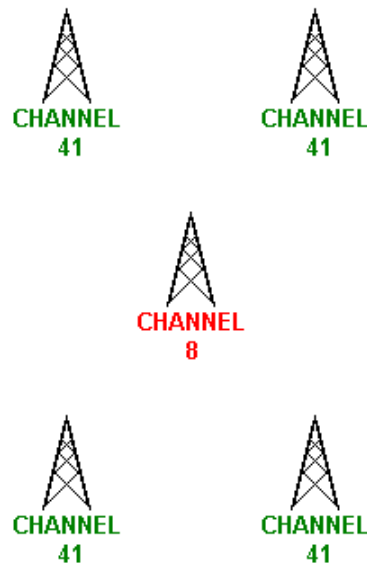
Because the delay of an on-channel repeater is intended to be short, it is usually not possible to regenerate the data and remove errors. Received signal distortions (including the short echo produced by the booster itself) are cumulative and are simply retransmitted.

Because of causality, on-channel repeaters can only add delay. Therefore, there is little flexibility in adjustment of timing. The possibility of regeneration puts a limit on power, further limiting flexibility of OCR systems.



Distributed transmission using
STLs: YES
off-air signals: NO
OCRs: YES

Distributed Translator Systems



Distributed translators using
STLs: YES
off-air signals: YES
OCRs: N/A

On-Channel Repeaters (OCRs) receive an off-air signal and retransmit it within about a microsecond. Most of the delay in an on-channel booster is from the IF bandpass filter, which is usually a surface acoustic wave (SAW) filter.

Figure 3 shows an OCR. The block diagram is similar to a translator, but the same LO is used for both the

Figure 4 – Comparison of Distributed Transmission with Distributed Translators

Figure 4 compares a channel 8 distributed transmission system (on the left) with a distributed translator system (at right). On the left, all of the transmitters are on the same channel, synchronized in frequency, data, and timing. The system on the left cannot use the off-air

signal of a “main” transmitter to feed the slaves, because of a minimum time delay of approximately 8 milliseconds associated with receiving, correcting, and re-encoding. This delay is far beyond what any receiver equalizer can correct. The emission from the outer “slave” transmitters would be delayed at least 8 milliseconds with respect to the “main” transmitter. The input to the slave transmitter needs to arrive at the slaves at least 4 milliseconds before the main transmitter emits. This system can therefore use STLs and OCRs, but not off-air signals.

On the right is a distributed translator system. In this system, the slave transmitters are all on a different channel than the main transmitter, so it does not matter that they are all delayed by 8 milliseconds or more. All that matters is that they synchronize with each other – not the originating transmitter. This system may use STLs or off-air receivers to supply data to the slave transmitters. Since the translators are an off-channel network, an on-channel repeater is not applicable.

Objectives for Distributed Translators

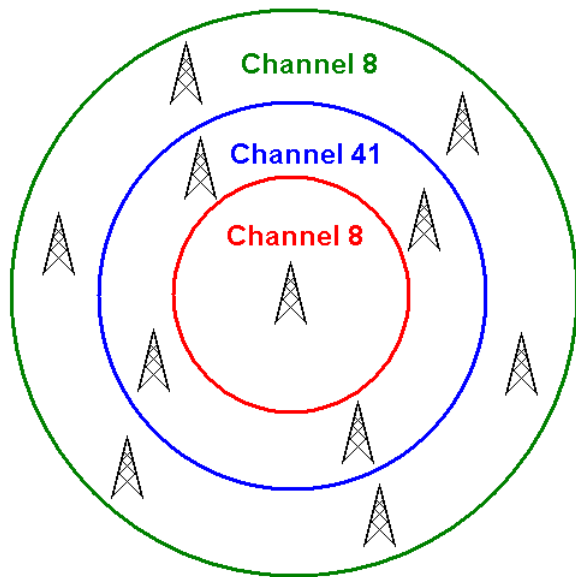


Figure 5 – Multihop Distributed Translator System

A basic distributed translator system should be capable of receiving an off-air ATSC signal at multiple sites, and retransmitting the signal on a different channel, with all translators synchronized to one another in frequency, data, and timing.

A further requirement in some applications will be for multihop transmission. Such a system would be able to receive a distributed translator’s signal, and retransmit it on yet another channel using multiple synchronized translators.

Figure 5 shows an example of a spectrally efficient two-tier distributed translator system. A main transmitter operates on channel 8. A first tier of distributed translators is on channel 41. The channel 41 translators are all synchronous with one another, and timing is adjusted to minimize skew in overlap areas. Beyond the channel 41 translator zone, the original transmitter’s channel 8 spectrum is reused with another tier of translators.

Distributed transmission techniques might seem simple to apply to translation applications, but several problems must be addressed. This paper looks at some details of the distributed transmission system in order to describe the problems, and to propose solutions.

Modifications to the SMPTE 310 Signal for Distributed Transmission

The distributed transmission adaptor, or DTxA mentioned above, makes three kinds of changes to a SMPTE 310 signal. These are:

1. Insertion of data into a distributed transmission packet (DTxP).
2. Periodic inversion of the MPEG sync byte (cadence sync).
3. Insertion of data into the MPEG error bit (field-rate side channel).

Figure 6 illustrates the modification to the SMPTE 310 data and its restoration at the slave transmitter. The first modification to the signal inserts data into the dummy placeholder packet generated by the station’s service multiplexer. This packet carries information to the slave transmitters, telling them where to set their timing, what identification sequence to use, the injection level for the identification sequence, the trellis coder states, etc. This packet ends up on the air, but the trellis coder state data must be removed.

The second modification of the signal inverts the MPEG sync byte every 624 packets. This periodic inversion is used to identify the insertion point for frame sync.

The third modification appropriates the MPEG packet header error bits (normally all zero) to communicate E-VSB data to the slave transmitters. This data is called the “field rate side channel.” The slave transmitters, having received this data, restore the bit to its zero state before airing the packets.

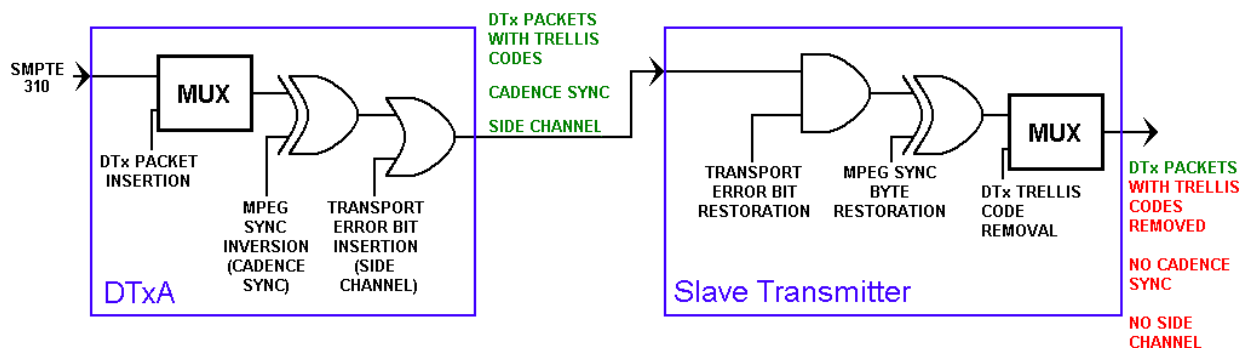


Figure 6 – Insertion of Data into SMPTE 310 and Its Removal

Problems with Broadcast of DTx Modified SMPTE 310

One of the problems associated with applying this technology to translator systems is that some of these modifications of the SMPTE 310 data are lost when the signal is transmitted over the air.

First, the trellis coder states must be removed from the DTxP before that packet goes on the air in a slave transmitter. This is to satisfy causality constraints, which is explained below.

Second, the MPEG sync bytes are not transmitted in the ATSC system, so it is not possible to invert them where they do not exist.

Third, the MPEG error bit in each packet must be restored to zero before transmission; otherwise receivers will reject the packets where the error bit is set, causing severe picture and sound breakup.

Fortunately, there are ways around each of these problems.

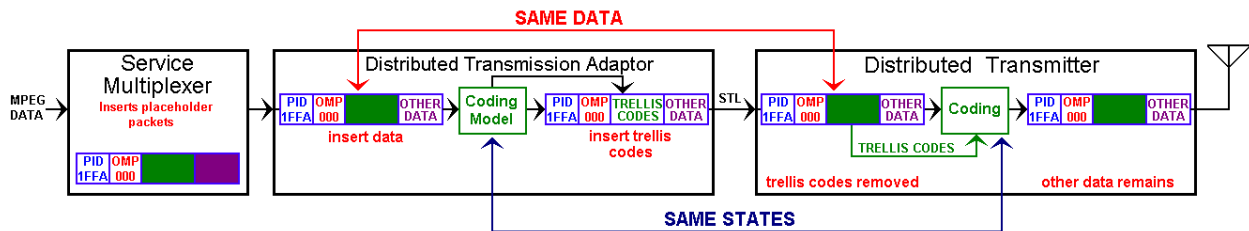
Removal of Trellis Coder State Data

Figure 7 shows the changes made to a Distributed Transmission Packet (DTxP) as it is processed at

The trellis coder states are created by a coding model in the DTxA. The coding model contains the same scrambling, interleaving, forward error correction coding, and trellis coding that exists in each transmitter. The purpose of the coding model is to accurately generate the same symbol sequence that will be produced by all of the slave transmitters. Only after the DTxP emerges from the coding model can the trellis codes be inserted. At this point, the DTxP is fully formed.

When the DTxP reaches a slave transmitter, the trellis codes must be removed before the packet proceeds into the coding process. This is because the coding process in each slave transmitter must exactly match the coding model in the DTxA. Not one bit of the input sequence can be different. Since the trellis codes did not yet exist when the DTxP entered the coding model in the DTxA, the trellis codes must be replaced by dummy data before the DTxP enters the slave transmitter's coder. Only in this way will the slave coders produce the same symbol sequence generated by the DTxA. Identical symbol sequences are essential for system synchronization.

This creates a problem. If the DTxP from an off-air signal transmitted from a slave transmitter is to be used for translators, the trellis codes are already gone. Trellis codes are essential for synchronization; without them, two transmitters will generate completely different symbol sequences, turning them into mutual jammers.



different points in a system. First, the DTxP is formed with dummy data in the station's service multiplexer. When the DTxP enters the DTxA, all data except for the trellis coder states are inserted into the DTxP. The trellis coder states cannot be inserted at this point because they do not yet exist.

Figure 7 – Changes to the Distributed Transmission Packet as It Passes through a System

MPEG Sync Inversion

When the DTx-modified SMPTE 310 bitstream is transmitted as an ATSC signal, the periodic inversion of the MPEG sync byte is lost. The periodic inversion is used to identify the position where ATSC frame sync is inserted. Fortunately, there is another way to determine the position of frame sync. The DTxP contains a pointer to the frame sync position. A value exists within the DTxP that identifies the packet number with respect to frame sync. The packet number value is an integer between 0 and 623, with frame sync appearing before packet 0. This value, although it may be received less often than cadence sync, provides the necessary frame sync phasing information.

MPEG Error Bit Usage

The problems associated with use of the MPEG error bit, since they only affect E-VSB, are discussed below in a separate section (“E-VSB Side Channel in Distributed Translator Systems”).

Single Tier Distributed Translator Operation

One simple way to form a single tier distributed translator network would be to use the station’s main transmitter as an “STL.” This is shown in Figure 8.

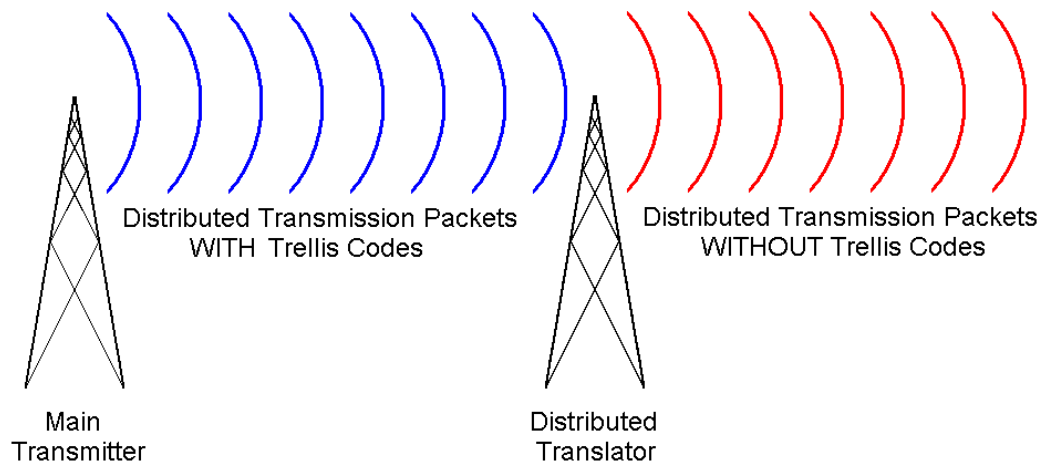


Figure 8 – Single Tier Distributed Translator Network

The main transmitter would transmit the complete DTxP. The main transmitter would not be operating in a slave mode, because it does not need to be synchronous with anything. It can simply pass the DTxP through, unmodified, with trellis codes intact. A single ring of distributed translators is possible with this approach. However, when the distributed translators receive the DTxP, they must remove the trellis codes before retransmitting the DTxP. So in this situation, the technology would limit the translators to single-hop applications.

Multiple Hop Distributed Translators

But, with a slight modification to the CS 110/A distributed transmission candidate standard, it would be possible to accommodate multihop distributed translator systems. The trellis code removal problem is solved, and multihop capability is made possible by transmitting multiple layers of DTxPs – one for each tier of translators. Figure 9 shows how this can be done.

In this example, there is a main transmitter surrounded by three tiers of distributed translators. The first tier receives its off-air signal from the main transmitter. The second tier receives an off-air signal from the first tier of translators. And the third tier receives an off-air signal from the second tier of translators.

There are three different kinds of DTxPs inserted – one for each tier of distributed translators. The first tier of translators removes the trellis codes from only the DTxPs addressed to it. The two other DTxPs pass through unmodified. This permits the trellis codes to reach the outer tiers of translators. The second and third tiers of translators remove the trellis codes from their corresponding DTxPs.

This is similar to what would happen if three DTxAs were cascaded. Each DTxA would insert its own DTxP, and pass along DTxPs generated by previous DTxAs.

However, it is important for test and measurement equipment to have access to all of the data in all of the DTxPs (except for the trellis codes, which must be removed). For the DTx non-trellis code

data from all translators to be present at the output of the last tier of translators, that data must be present before the first DTxA coding model. So, a special multihop DTxA must insert all the DTxA non-trellis code data (shown as “other data” in Figure 9) into all layers of the DTxA packets. The system would be similar to a cascade of conventional DTxAs except in this detail.

tiers of translators. An alternative would be to use the

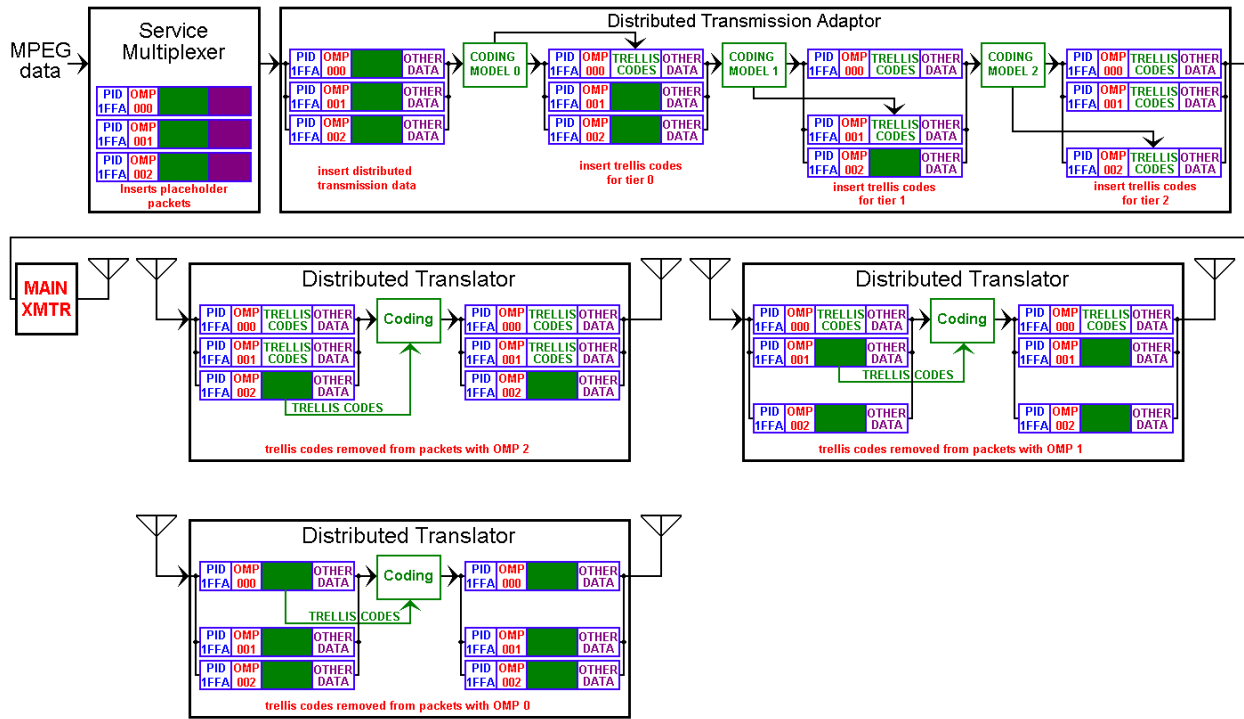


Figure 9 – Distributed Transmission Packet Processing in a Multihop Distributed Translator System

first byte of reserved data within the DTxP to address translator tiers.

Distributed Transmission Packets (DTxPs)

Figure 10 shows the structure of a DTxP.

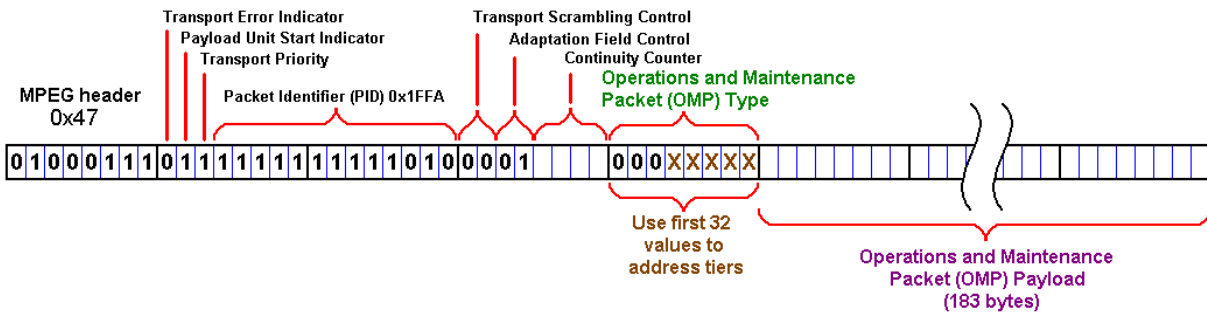


Figure 10 – Distributed Transmission Packet Structure

The DTxP starts with a MPEG sync byte. Following this, there are some standard header bits. Packet Identifier (PID) 1FFA is reserved for “operations and maintenance” (OMP) packets. The first byte within the MPEG packet payload, the OMP type byte, identifies the kind of OMP being sent. (At the present time, there is only one kind of OMP – the DTxP.) DTxPs can be associated with a particular tier of translators through the use of the OMP type byte. If we reserve the first 32 states of this byte to indicate which tier of translators is being addressed, we can associate DTxPs with up to 32

In the case of analog television, doing a 32-hop translator system would accumulate some significant signal degradation. But 32 tiers of translators are not

out of the question for digital television, since the signal is regenerated at every hop. So, the picture quality at the end of the translator chain should be just as good as the output from the main transmitter (assuming no uncorrected transmission errors).

Distributed Translator Delays

Figure 11 shows what the delays look like in a translator system. In a receiver, there is typically 100 microseconds of delay or more associated with root-raised cosine (RRC) bandpass filters, adaptive equalizers, and demodulation to symbols. An additional

4000 microseconds of delay is caused by deinterleaving and error correction. A typical translator may employ 1000 microseconds of data buffering, to allow for propagation changes and other sources of timing variation. The transmitter will also incur a 4000 microsecond delay for data interleaving, and at least 50 microseconds for modulation and filtering. The sum of all of these delays determines the minimum interval for timing between successive translator tiers – roughly 10 milliseconds. As the signal proceeds through each tier of translators, it must incur at least this minimum amount of delay.

Distributed Translator System Topologies

There are several possible arrangements for implementing multiple tiers of distributed translators. One such layout is shown in Figure 12.

In this example, the main transmitter is on channel 8. Two tiers of translators exist on channels 41 and 26. One of the second tier translators is able to receive a direct signal from the main transmitter instead of from the first tier of translators. The arrow in the diagram above shows the direct propagation path. This kind of operation is theoretically possible. It is necessary for the slave transmitter at the second tier to strip the trellis codes from its own DTxPs, as well as from the DTxPs

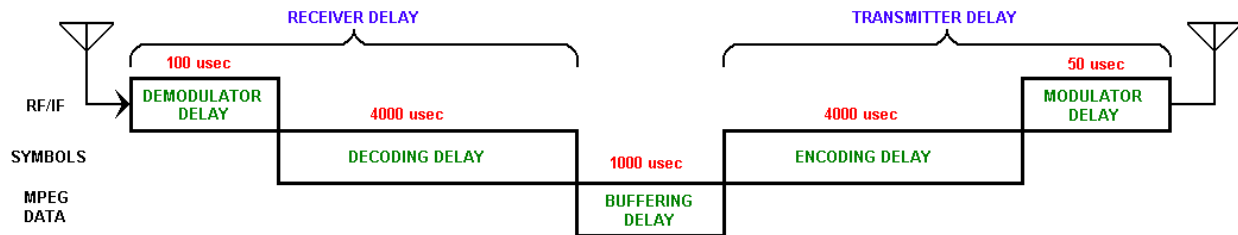


Figure 11 – Delays in a Distributed Translator

addressed to the first tier of translators.

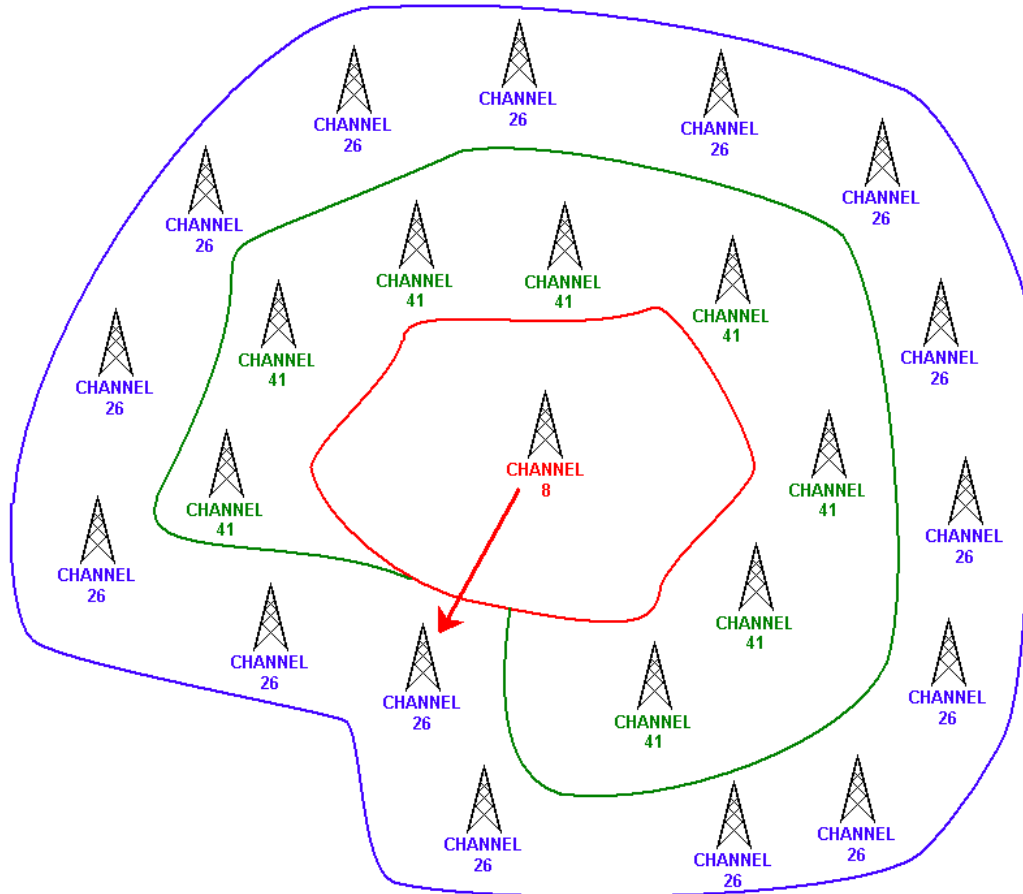


Figure 12 – Skipping a Translator Tier

So, it is possible to skip tiers of translators as long as the slave transmitter removes trellis codes from the “unused” intermediate DTxPs. However, it is not possible to “backtrack” – to translate from an outer tier to an inner tier, as shown below in Figure 13.

E-VSB Side Channel in Distributed Translator Systems

The DTx system includes a field-rate side channel, which is used mainly for E-VSB applications.

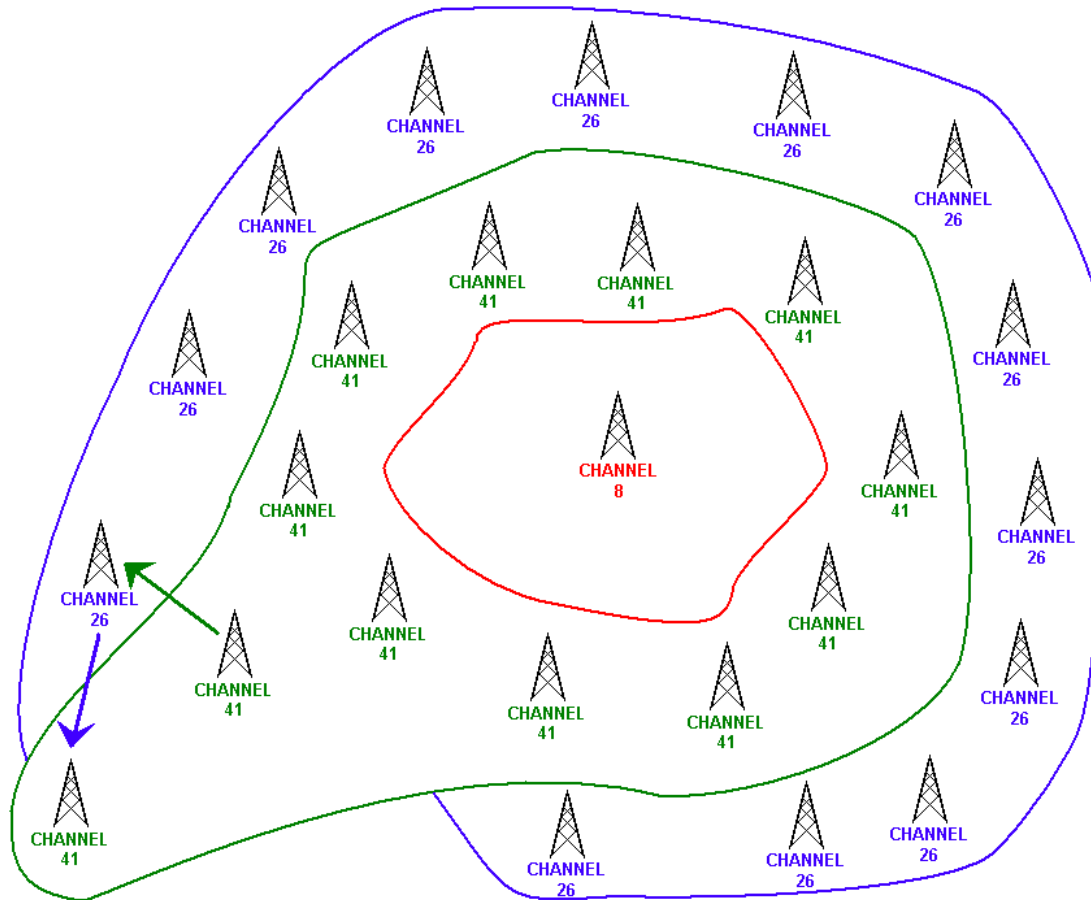


Figure 13– Backtracking Distributed Translators Cannot Be Done

Here, it might seem possible to feed a first tier translator with an off-air signal from the second tier of translators. But, this situation cannot work because of timing. Referring to figure 11 above, each successive tier of translators must be delayed by about 10 milliseconds or more with respect to the one before it. So, the channel 41 translator, even though it might be able to receive a channel 26 signal, would not be able to achieve the correct system timing to match the rest of the channel 41 translators, because their emission time comes *before* the off-air channel 26 signal it is receiving. There is an additional reason this arrangement cannot work: the DTxP associated with the first-tier channel 41 translators has had its trellis codes removed by the time it is radiated by the second-tier channel 26 translator.

The DTxP may be transmitted as often as once per field, but more typically it will be sent about once per second. However, when transmitting E-VSB, the ATSC field sync reserved bits may need to change on a field by field basis. This creates a need for a way to communicate the reserved bits on a field basis to synchronize transmitters which are being used for E-VSB.

This is the purpose for the field-rate side channel. The field-rate side channel is formed by appropriating the MPEG header error bit (“transport error indicator” in figure 10 above), which is normally always zero. There are 312 such bits present in a field. After the E-VSB data reaches a slave transmitter, the transmitter clears the error bits to zero before transmitting the MPEG packets.

It is known from experiments that transmitting data using the MPEG error bit affects receivers with severe picture breakup. So using a station’s main transmitter as an “STL” for a translator network will not work with a side channel present in the MPEG error bit. Receivers

will reject MPEG packets with the error bit set. So, using the MPEG error bits for over-the-air operation of the side channel is not an option.

However, there are three possible methods for using E-VSB in a distributed translator network. They are:

1. Take E-VSB data off the air, using a special receiver that can recover data from the field sync.
2. Transmit the side channel using the priority bit of the MPEG header.
3. Transmit the side channel in a field rate OMP packet.

Option 1: the distributed translator system can transmit all of the timing information, trellis codes, etc., but it cannot transmit the side channel in the MPEG error bits. But, the E-VSB data, including the VSB mode bits and the field sync reserved bits, may be taken off the air and retransmitted. This will require a special receiver for the E-VSB mode that can recover and output these bits. This special receiver would only be required for E-VSB distributed translators. No special receiver is required for distributed translators with conventional ATSC signals.

Option 2: the side channel could be changed from using the MPEG header error bit to the MPEG header priority bit. The priority bit is apparently not currently used in the ATSC system. So, the side channel could possibly be transmitted over the air this way. Evaluation of receivers would be necessary to determine whether use of the priority bit would affect them.

Option 3: another way to make E-VSB work with multiple levels of distributed translators would be to move the field rate data into the DTxP's reserved bits. Then, the DTxP transmission rate could be increased to once per field if necessary (using 0.32% of the channel capacity per tier of distributed translators). Or, the E-VSB system could be operated such that a DTxP is only transmitted when the E-VSB packet mix ratio or field sync reserved bits need to change.

Conclusions

Although the distributed transmission system was originally conceived for use with STLs, it is possible to make slight system modifications to create distributed translator networks, using off-air signals as the signal delivery system.

A single-tier distributed translator system is possible with no modifications to CS110/A. A multiple hop translator system will require allocation of OMP values.

The spectral efficiency obtained by using as little as just one additional channel for an entire translator system

makes it possible to operate ATSC translators along with NTSC translators during the transition phase.

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