DTV Channel Characterization

I. Garrison, R. Martin, W. A. Sethares, B. Hart,
W. Chung, J. Balakrishnan, R. Casas, T. Endres,
M. Larimore, P. Schniter, C. R. Johnson, Jr.

Jan 2001

Abstract

This paper describes the methods used to gather and process a large database of measured DTV channels. It begins with an overview of the kinds of channels encountered and the kinds of equalizers needed to undo the effects of the channels, and concludes with several implications for the design of 8-vsb HDTV receivers.

I How the Data Was Gathered

In August 1999 the authors, in affiliation with NxtWave Communications, AST, Cornell University Blind Equalization Research Group (BERG) and the Australian National University Telecommunications Group, travelled to Philadelphia to make measurements of DTV channels in the field. A variety of antennas and locations provided a variety of different kinds of channel impairments.

II Description of the Processing

The raw data was processed using the BERG's SnapperWare, which is a block oriented software receiver. After demodulating the signal, it is equalized using a blind adaptive method with both feedforward and DFE structures. After initial convergence, the estimates are refined using a decision directed method. Then the output of the equalizer is used to compute a linear model that represents the transmission channel.

III Data Analysis

Within the data records we looked at, we found features which are expected to impact the capability of 8-CSB receivers. These features include:

- Decision feedback error propagation (processing problem)
- Cycling (processing problem)
- Pilot and band edge distortion
- Severe passband nulls
- Large echo
- Smearing (of main peak)
- Time variation

The processing problems will be discussed specifically after the analysis of the example data records. Also note that all references to 'frames' refer to 64 kilobyte blocks in the data records. Full data records are broken into these frame segments for block processing. Several example channels are described below (all movies referenced are located at http://backhoe.ee.cornell.edu/BERG/... .../downloads/movies/).

A hampton248a

Hampton248a is an an example of the best channel we found in the field. It has a fairly nice spectrum, with good SNR. Although the magnitude of the passband varies by approximately 5 dB between the upper and lower band edges, this does not cause any trouble with equalization and as you can see from the eye diagram in figure 1, the eye is open, and we have

NEED A PICTURE HERE...GOTTA RUN THE DATA

B luzerne8

Luzerne8 is a channel with both lower band edge and pilot distortion. More specifically, the lower band edge (from approxmiately 3 to 5 MHz) is about 10 dB below the average passband value. In addition, the pilot is also attenuated, and is approximately 10 dB below the average passband as well. The frequency response of this channel is shown in figure 2 (response and eye diagram over full data record can be seen in luzerne8SPED.mov).

This level of attenuation does not appear to cause too much trouble with equalization, as is seen by the fact that the eye diagram in the lower plot of the movie referenced above shows distinct bands for most frames. However, one frame does exhibit decision feedback error propagation, and five others show poor equalization. (The effect of error propagation on data analysis will be discussed in the section titled 'Error Propagation.') Even with these slight difficulties, this is a fairly benign channel.

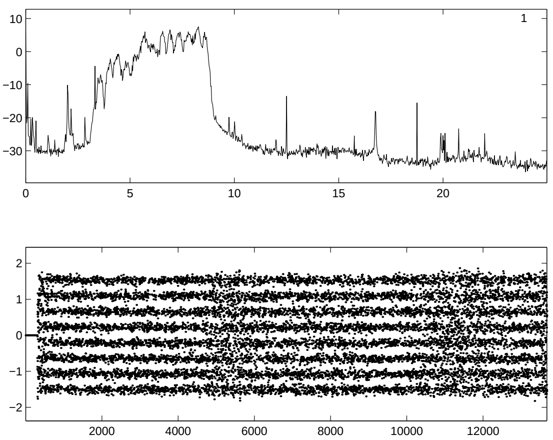

Figure 1: Spectrum and Eye Diagram for First Block of luzerne8

C mantua7

Mantua7, like luzerne8, exhibits pilot and lower band edge distortion. Here, the pilot is approximately 7 dB below the mean passband level, and the lower band edge (from 5 to 6 MHz) is 13 dB below the passband average. In addition to this the upper band edge is slightly rounded, and there is a trought of about 5 dB centered at 7 MHz. In general, the entire passband is more ragged than luzerne8. This causes more problems with equalization, as the bands in the eye diagram are not as distinct as in luzerne 8 (see figure 3 or mantua7SPED.mov). Also, there is evidence of error propagation in 2 of 31 frames, and nine more show very poor equalization.

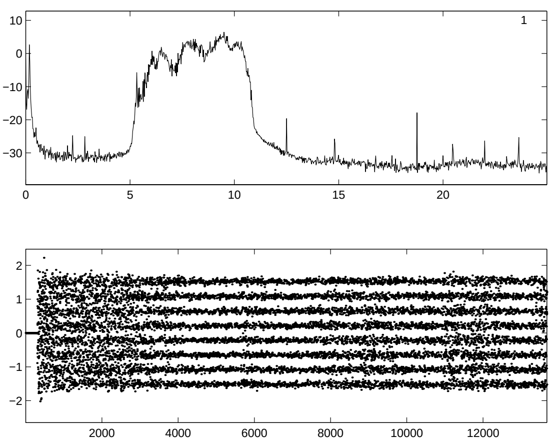

Figure 2: Spectrum and Eye Diagram for First Block of mantua7.

D hampton328e

This channel has a very deep and wide null directly in the middle of the passband (from 7 to 9 MHz, 20 dB maximum attenuation). This null essentially eliminates the frequency components between 7.5 and 8 MHz, making recovery impossible (figure 4 or hampton328SPED.mov). Although the rest of the band is nice (large pilot, little band edge attenuation), the null in the center results in decision feedback error propagation in all 31 blocks processed.

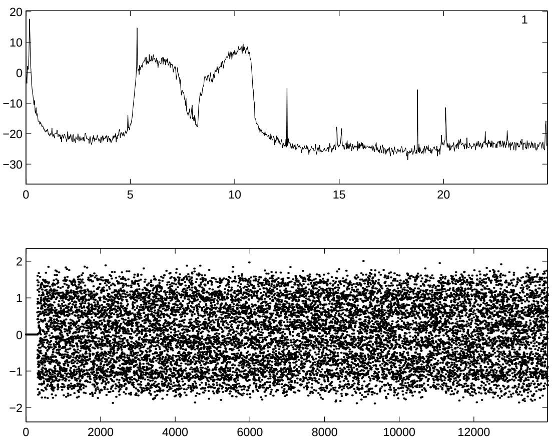

Figure 3: Spectrum and Eye Diagram for First Block of hampton328e.

Another thing to note about this channel is that it shows the best evidence of time variation of the short records examined in this paper. The time variation provides further difficulty in creating an equalizer, as it must adapt continuously to the changes. This will be further discussed in section 4.3.

E hampton328k, hampton328l, hampton328g

The reason for mentioning these channels, in addition to hampton328e above, is not for their individual characteristics, but, rather, the difference in their individual characteristics. Each of these channels was obtained at the same location, with different antennas orientations. Different antennas (Yagi and generic television antennas (i.e. rabbit ears)) and/or orientations were used for each of these captures, and, as a result, the observed channel can be seen to differ greatly (see figures 5 through 7)

F delair3

The channel model for delair3 indicates a large echo about 15 dB below the main peak at a delay of 15 microseconds. Thhere are also several minor echos about 23 dB below the main peak, lying within 8 microseconds of the

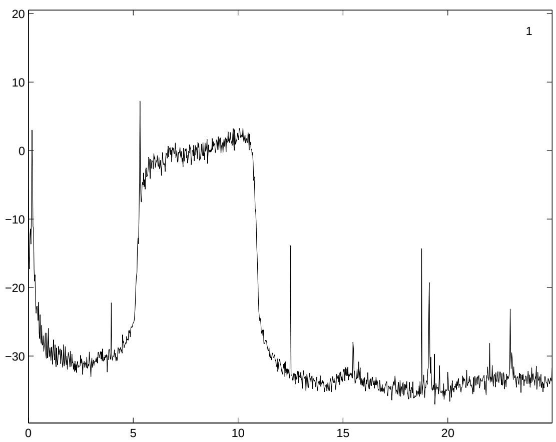

Figure 4: Spectrum for First Block of hampton328k

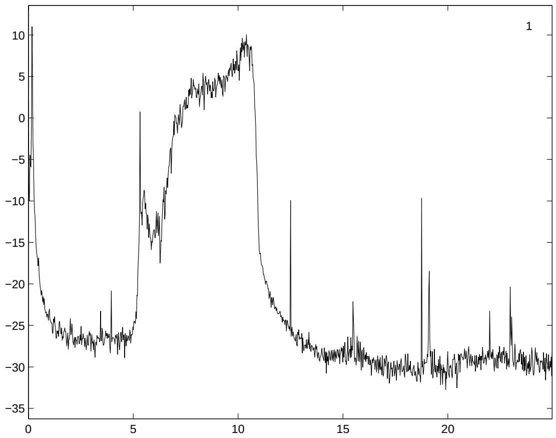

Figure 5: Spectrum for First Block of hampton328l

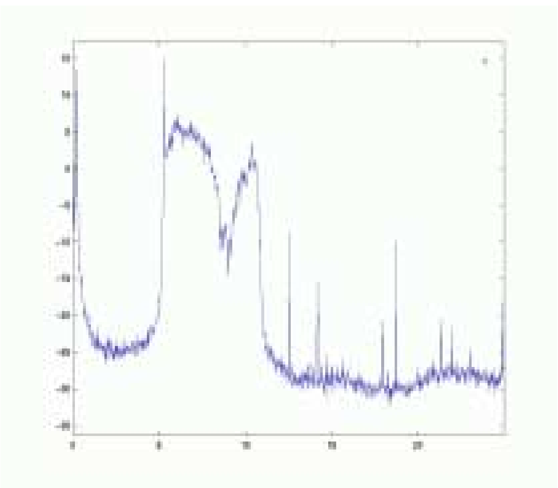

Figure 6: Spectrum for First Block of hampton328g

main peak. Not surprisingly, the frequency response of this channel is fairly nasty with 10 to 15 dB attenuation for frequencies between 3 and 7 MHz (figure 8 or delair3SPED.mov).

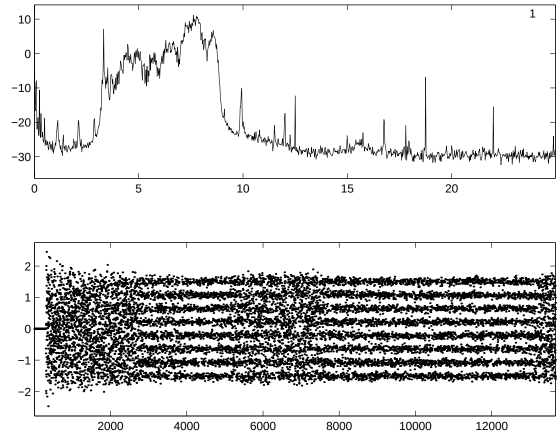

Figure 7: Spectrum and Eye Diagram for First Block of delair3

IV Feature and Processing Problem Review

The following sections review the features observed in the specific channel analyses above, but group the features as categories with references to the channel records for support. Here, the focus is on the features and implications they might have, rather than the observation of their existence.

A Pilot and band edge distortion

Severe band edge or pilot distortion can have undesireable consequences for synchronization algorithms that rely on relatively undistorted band edges or pilots. Such distortion is readily apparent in the spectra of luzerne8 (figure 2) and mantua7 (figure 3).

B Severe passband nulls

Severe passband nulls are anethematic to a baud-spaced linear equalizer attempting to construct a delayed inverse of a channel. Spatial diversity or oversampling might help overcome the problems caused by nulls such as the one in hampton328e (figure 4).

C Long delay spread

A long delay spread in a channel, such as the one in delair3 (figure 8), indicates the need for a long equalizer to open the eye. It also shows that the pn training seqence of length 511 is all but useless in some channels, thus demonstrationg the need to do blind adaptation in place of, or in addition to training-based methods.

D Decision feedback error propagation

Due to the intended operation of DTV in a low SNR environment, decision error feedback propagation can have such an impaact that its removal via feedback of the decoder outputs rather than the memoryless slicer outputs is required. Evidence that decision feedback error propagation results in failed equalization is shown figure 9 which shows the eye diagram and log-scaled channel model for the first block of hampton328e. The error propagation is evidenced by the plateau of taps 30 dB below the peak in the channel model. This plateau is the same length as the DFE and causes failed equalization as can be seen in the eye diagram. However, the large taps and spectrum of the model we determined appear to still be accurate. This is shown by viewing the movie luzerne11CMSP. From this you can see that although error propagation appears in some of the blocks processed, the change in the spectrum and the large taps in the channel model is no more than between any two successive blocks that show no error propagation.

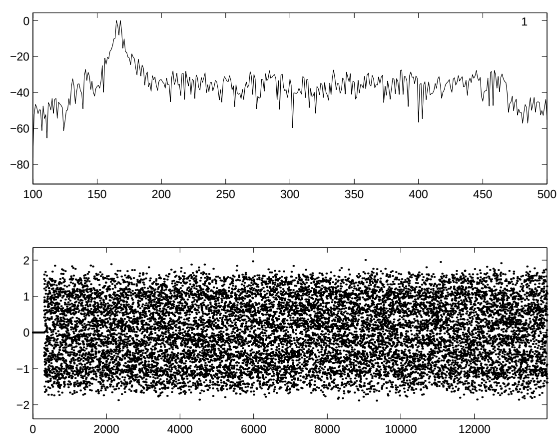

Figure 8: Channel Model and Eye Diagram for First Block of hampton328e.

E Orientation issues

Since orientation appears to matter a great deal for reception (see hampton328e, hampton328k, hampton328l, and hampton328g (figures 4 through 7)), directional antennas may be hard pressed to obtain a good signal without some diversity or higher-level tracking control. This can be complicated in a highly time-varying environment, so omnidirectional antennas seem to be the optimal choice for reception.

V Other Potential Issues

In addition to the problems discussed above, other issues are expected to arise in DTV channel reception. These include:

A Time variation and bobbing channel

Channel variations caused by the motion of physical reflectors in the vicinity of the receiver need to be tracked by an adaptive receiver. What would seem to be the most difficult of such changes to track are sharp changes in the desired equalizer parameterization caused by relatively modest changes in the channel impulse response coefficients altered by relatively mobil reflectors. In this light, one of the worst effects would be due to a channel zero slowly wandering back and forth across the unit circle. When inside, the optimum (length-unconstrained) linear equalizer (which will have the same denomenator as the decision feedback polynomial in the absence of decision feedback errors) will effectively canvel the zero with a pole and no forward equalizer component (numerator) singularities. When (just) outside, however, the forward equalizer will have to build a long impulse that incorporates the non-minimum phase channel zero in a ring of evenly spaced zeros provided by the forward equalizer. Thus, the equalizer's forward component parameters would be expected to enact a sizeable jump change in their values. Unfortunately, we were unable to isolate an example of this type of variation due to the length of the data captures being too small to allow for the observation of all but the fastest time variations.

A more mundane type of time variation is movement of the channel and equalizer parameters at about the same rate induced, e.g., by fluctuations in the channel frequency response. These time variations are readily observed in the variations of the received signal spectrum. However, we were unable to find channels within our data records that showed significant time variation over the short length of our data records. Of the time variations we did find, the best example is shown in hampton328eSPED.mov.

B Equalizer length

From the channels obseverved, it appears that the presence of long delay spreads will be an frequent issue in constructing an adequate equalizer. In the urban environment in which out channel data was captured, we frequently found channels with significant echoes hundreds of taps after the main peak. This indicates that for proper equalization, the forward equalizer and DFE must be several hundred taps long.

VI Discussion and Conclusions

Each of the above scenarios shows a situation that may cause problems for the equalizer in the receiver, and possible ways of countering these problems are readily conceivable. However, it is almost impossible to know *a priori* which situation will actually be encountered in any given setting. This suggests that a "higher level" of control must be considered, one which uses meta-information derived from the received data in order to set the parameters in a useful way. For instance, consider that the system may change from a "simple setting" (one where the channel is effectively a single spike) to a complex setting in a short time. It probably does not make sense to adapt (say) 600 taps in the equalizer in the former situation, whereas all 600 may be crucial in the latter. More seriously, the channels may easily vary so that no single "setting" can always work. This highlights one of the chief advantages of a "software driven" receiver - a higher level of control can be used to intelligently set parameters.