DTV Channel Characterization

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Abstract — **This paper describes a database of measured terrestrial Digital Television (DTV) channels to be made available on the web to stimulate research in the improvement of future DTV receivers. Features that are likely to impact the capability and design of 8-VSB HDTV receivers are studied by processing the data. Frequency and time-domain channel models depicting these features are provided and their implications on the design of 8-VSB receivers is discussed.**

I. Introduction

Terrestrial television broadcast is set to switch entirely to a DTV standard in 2006. This creates a need to determine the characteristics of DTV channels by that time to prepare for the issues that may arise. In addition, there is still a debate about what the final standard will be, whether it will be COFDM or something else, and the benefits and drawbacks of different modulation schemes are important to consider in this decision.

In March 2000 the authors, in affiliation with NxtWave Communications, Applied Signal Technology, Inc., Cornell University Blind Equalization Research Group (BERG) and the Australian National University Telecommunications Engineering Group, traveled to Philadelphia to make measurements of terrestrial DTV channels in the field. The measurements were taken using a directional (Yagi) antenna and an omni-directional antenna. A variety of urban, sub-urban and rural locations presented a variety of different kinds of channel impairment.

The raw data was processed using the BERG's SnapperWare (a block oriented software receiver) embedded in AST's Model 990DTV Digital Television Signal Analysis System. The channel estimation method utilized is, in principle, the Gooch-Harp method[1] (LMS channel identification using pre-equalized data and decisions based on the blindly equalized data).

After demodulating the signal, it is passed through a baud-spaced ARMA filter which blindly equalizes the channel using the IIR CMA algorithm[2]. After initial convergence, the estimates are further refined using a decision-directed method with a DFE structure, where the DFE filter is initialized by the auto-regressive part of the previous ARMA filter. Then the output of the decision-directed equalizer is used as a reference signal to identify the transmission channel from the pre-equalized data.

Using this structure, we could process multiple blocks at intervals within a data record and use these to construct plots of channel characteristics (e.g. spectrum, channel model). These can then be viewed consecutively to produce a simple movie that shows time variations within the channel.

II. Data Analysis

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

- Pilot and band edge distortion
- Severe passband nulls
- Long delay spread
- Time variations
- Decision feedback error propagation (processing problem)

Supported by an REU supplement to NSF Grant ECS-9811297

The processing problems will be discussed separately after the discussion of the sample data records. All references to 'blocks' refer to 64 kilobyte blocks (about 12,800 symbols) in the data records. Full data records are broken into these block segments for block processing. Several example channels are described below (the movies referenced below show channel characteristics over the entire data record and are located at

http://backhoe.ee.cornell.edu/BERG/downloads/movie
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and raw data will be made available upon request to our website).

A hampton248a

Hampton248a is an an example of the more benign channels we found in the field. It has a fairly flat spectrum (figure 1), with a high SNR (35 dB). 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.

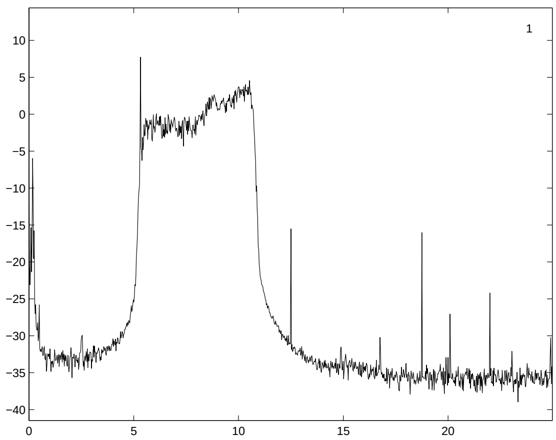

Figure 1: Spectrum for First Block of hampton248a

B luzerne8

Luzerne8 is a channel with both lower band edge and pilot distortion. More specifically, the lower band edge (from approximately 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).

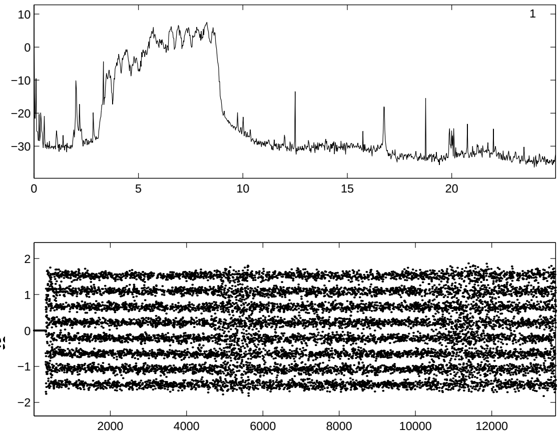

Figure 2: Spectrum and Post-Equalized Eye Diagram for First Block of luzerne8

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 blocks. However, one block 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.

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 trough 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 seen in the bands in the eye diagram that 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 blocks, and nine more show very poor equalization.

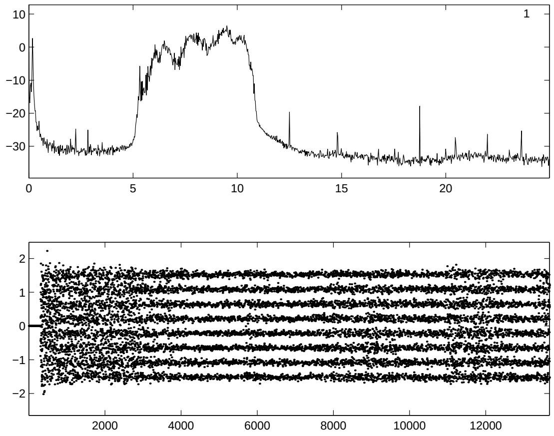

Figure 3: Spectrum and Post-Equalized Eye Diagram for First Block of mantua7.

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, inhibiting recovery (figure 4 or hampton328SPED.mov). Although the rest of the band is fairly flat (large pilot, little band edge attenuation), the null in the center results in decision feedback error propagation in all the 31 blocks processed.

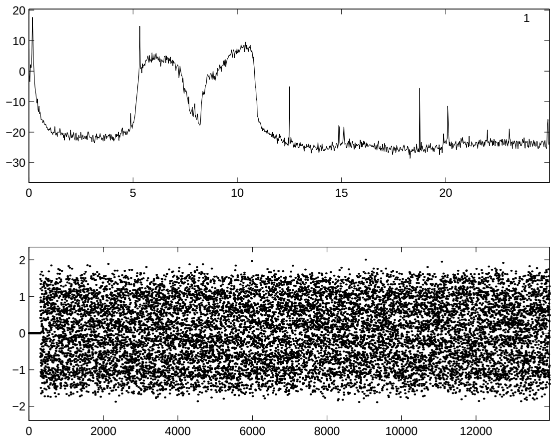

Figure 4: Spectrum and Post-Equalized Eye Diagram for First Block of hampton328e.

This channel exhibits the best evidence of time variation (seen by fluctuation in the spectrum) in 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 IV.A.

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. A Yagi antenna with different orientations was used for each of these captures, and, as a result, the observed channel can be seen to differ greatly (see figures 5 through 7)

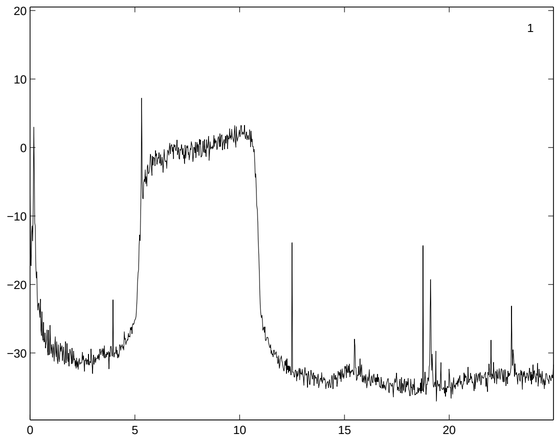

Figure 5: Spectrum for First Block of hampton328k

F delair3

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

III. Feature and Processing Problem Review

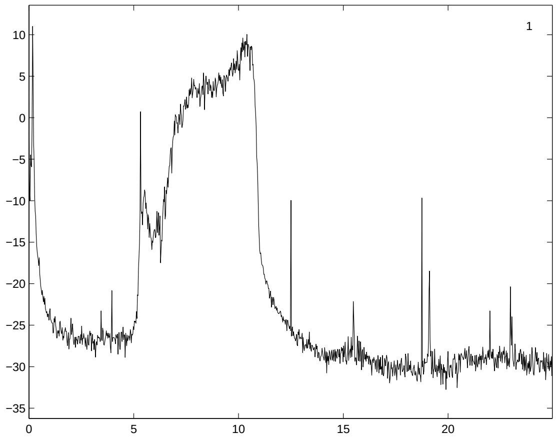

Figure 6: Spectrum for First Block of hampton328l

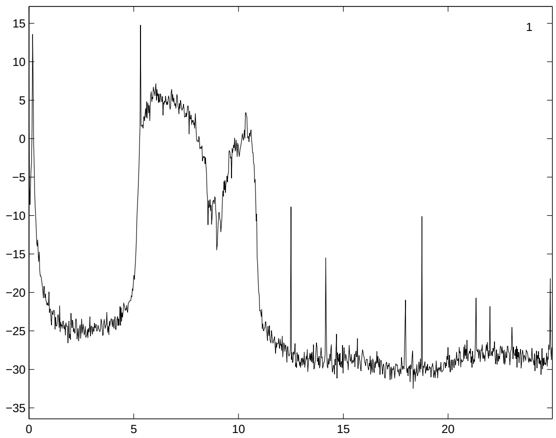

Figure 7: Spectrum for First Block of hampton328g

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.

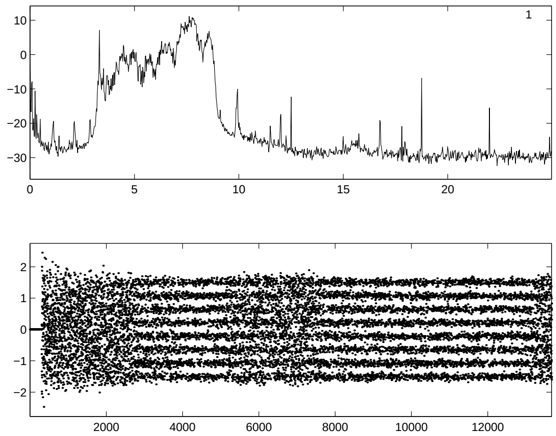

Figure 8: Spectrum and Post-Equalized Eye Diagram for First Block of delair3

A Pilot and band edge distortion

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

B Severe passband nulls

Severe passband nulls is an impairment to a baud-spaced linear equalizer attempting to construct a delayed inverse of a channel. The use of a DFE may mitigate the effect of the severe null to some extent [4], and 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. Hence the PN training sequence of length 511 is insufficient for a trained adaptation of the equalizer. This demonstrates 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 impact that its mitigation 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 in 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.

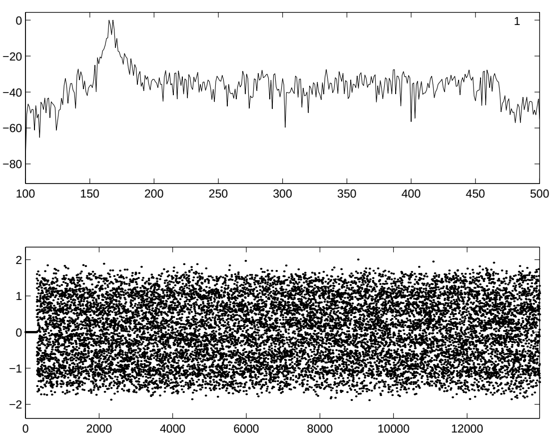

Figure 9: Channel Model and Post-Equalized Eye Diagram for First Block of hampton328e.

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 with smart processing may prove to be more robust.

IV. 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 mobile 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 denominator as the decision feedback polynomial in the absence of decision feedback errors) will effectively cancel 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 conclusively an example of this type of variation in our short data captures.

A typical 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 observed, it appears that the presence of long delay spreads will be a frequent issue in constructing an adequate equalizer. In the urban environment in which our 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.

V. 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.

References

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