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DVB-T for mobile microwave links

D. van Kemenade, A. van Roermund* ***and*** **J. Zubrzycki**

***Chairman of the Mixed-signal Microelectronics Group at Eindhoven University of Technology**

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Abstract

DVB-T is a transmission standard that enables good reception even when the transmission channel is subject to frequency-selective fading. When DVB-T is used for a mobile microwave link, flat fading can occasionally occur. In this article, a time interleaving layer is proposed that makes the transmission more rugged under flat fading conditions. The proposed mechanism involves an additional Reed-Solomon coding step and a modified data transmission order, and preserves the DVB-T layer of the communications channel.

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Key words: DVB-T, microwave links, time interleaving, forward error coding

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DVB-T FOR MOBILE MICROWAVE

FLAT FADING CAN OCCASIONALLY OCCUR WHEN DVB-T IS USED FOR A MOBILE MICROWAVE LINK. HOWEVER, THE USE OF A TIME INTERLEAVING LAYER COULD HELP MAKE THE TRANSMISSION MORE RUGGED.

by D. van Kemenade, A. van Roermund and J. Zubrzycki

DVB-T, the transmission standard used for digital terrestrial television, combines several TV channels into a single data stream that is then broadcast using COFDM (Coded Orthogonal Frequency Division Multiplexing). COFDM is a spread-spectrum technique that disperses the data over a large number of carriers. If some carriers are corrupted by a fade or interference, the data can be recovered from the remaining carriers through forward error coding. This makes DVB-T highly suited to channels with frequency-selective fading due to multipath propagation (ghosting).

Because of its resilience under difficult transmission conditions, DVB-T is now also increasingly used for mobile microwave links. An example of a possible application is the digital radio camera developed by BBC Research & Development (See image on left).

LINKS

However, from time to time the path between transmitter and receiver is temporarily blocked, or very short delay reflections of the signal interfere with the direct signal. This can result in flat fading, which renders most carriers unusable. For mobile microwave links, an additional layer between the data source and the actual DVB-T modulator could help overcome brief flat fades.

FADING CHANNELS

As a result of reflections, there will generally be multipath reception. The several paths from transmitter to receiver are associated with different delays, leading to dispersion of the signal in time. Those different delays are displayed in a delay profile, as shown in Figure 1.

From the delay profile, the multipath spread of the channel, T_m, can be determined. From T_m it is possible to calculate the coherence bandwidth:

$$(\Delta f)_c \approx \frac{1}{T_m}$$

If the coherence bandwidth is small compared to the bandwidth of the transmitted signal, frequency-selective fading occurs. There will be notches in the spectrum of the received signal. As a result, not all COFDM carriers can be received because they are too much attenuated. The DVB-T standard offers protection against this, as it employs frequency interleaving to spread the data across the carriers. Even if a large proportion of the carriers cannot be received properly, the original data can still be reconstructed from the remaining carriers.

This is no longer possible in the event of flat fading, also called frequency-nonselective fading, when all carriers are severely attenuated. This occurs when the coherence bandwidth is large in comparison with the signal bandwidth, i.e., when T_m is small. This happens when two or more signal paths arrive at the receive antenna with only short delay difference. Their sum may add up constructively or destructively, sometimes leading to total cancellation or fading. Figure 2 depicts the received signal power after transmission over a flat fading channel.

The depth, number and duration of the dips in Figure 1 are a function of the maximum Doppler frequency, which in turn depends on the carrier frequency (f), the speed of the mobile transmitter (v) and the speed of light (c):

$$f_d = \frac{v \times f}{c}$$

The distance between two local amplitude minima in Figure 2 is approximately equal to the coherence time of the channel, which can be calculated from the maximum Doppler frequency:

$$(\Delta t)_c \approx \frac{1}{2 f_{\text{dop,max}}}$$

For high transmitter speeds, the maximum Doppler frequency will be high, so the distance between maximums and hence the length of deep fades will be short. In this case, flat fading can be overcome with time interleaving. Just as frequency interleaving allows erroneous data to be corrected from information obtained from carriers with different frequencies, time interleaving allows recovering data from information transmitted before or after the flat fading event.

The DVB-T standard does not offer time interleaving, as it was primarily designed for stationary receivers. However, for mobile microwave links it seems beneficial to extend the DVB-T system with an additional layer that provides time interleaving.

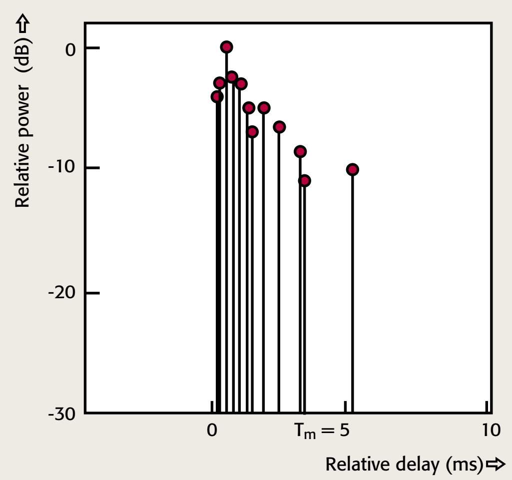

FIG. 1 DELAY PROFILE FOR A TYPICAL URBAN ENVIRONMENT

PROPOSED TIME INTERLEAVING LAYER

There are two error-coding stages in DVB-T: "inner" convolutional coding and "outer" Reed-Solomon coding. This approach combines the error correction capability of convolutional codes at the bit-level with the short burst error-correction capability of Reed-Solomon coding at the byte level. Note that there are interleavers in the existing DVB-T system. The outer interleaver maximises the performance of the two error-coding stages by breaking long burst errors down into shorter ones, while the inner interleaver is used for the frequency interleaving process. These two existing interleavers introduce a delay of only a small number of packets, which is insufficient to overcome long burst errors seen in mobile microwave links. Hence an external time interleaving layer is proposed [the authors are aware that a similar idea has been proposed independently for other applications].

The modulator accepts 188-byte data packets, the first of which is the sync byte. To implement the time interleaving layer, a number of the remaining 187 bytes are set aside for an additional Reed-Solomon error-coding step. If 2t bytes are available for RS parity bytes, the payload can still be reconstructed even if t bytes anywhere in the packet are corrupted after reception. Reed-Solomon was chosen for additional error coding because the flat fading that the time interleaving mechanism intends to overcome results in bursts of errors.

The incoming data is first RS (187, 187-2t, t) coded. The N packets that are formed in this way are stored in rows of a memory. The memory is then read out in columns. The 188-byte DVB-T packet is formed by the sync byte followed by 187 bytes from the memory column.

In the event of a deep fade, a number of packets will not be received correctly. Assume that N×t / 187 consecutive packets are corrupted. In the time de-interleaver in the receiver, the data is written into memory columns and read out in rows, so that we have 187-byte error-coded data packets again. Each of these N received packets contains t corrupted bytes. However, up to t bytes can be corrected by the RS-code so the original 187-2t payload bytes can be reconstructed.

REQUIRED INTERLEAVING DEPTH

The time it takes to transmit the N×t /187 corrupted packets is 188/187×N×t divided by the data rate in bytes/s. This DVB-T data rate depends on the chosen modulation mode, e.g., 64-QAM rate ½ with a $^1/_{32}$ guard interval has a data rate of 2.262×10^6 bytes/s. As long as the duration of the correctable portion calculated here exceeds the maximum error burst time T_{burst} caused by the deep fade, the video data can be received correctly:

$$\frac{188}{187}\times\frac{N\times t}{data\_rate} > T_{burst},$$

where the T_{burst} is in seconds and the data rate in bytes/s. So the interleaving depth N needs to be:

$$N=\left\lceil T_{burst}\times\frac{187}{188}\times\frac{data\_rate}{t}\right\rceil \text{packets}$$

T_{burst}, the length of the bursts we want to overcome with time interleaving, depends on the noise distribution of the channel and its Doppler spread.

Now consider a real-life application to get some idea of the numbers involved. Assume that we want to use 64-QAM rate ½ with a guard interval of $^1/_{32}$ and we need 141 bytes per DVB-T packet for the data we want to transmit. This leaves 187-141 = 46 bytes for the additional RS coding step, hence t = 23.

To find out how large T_{burst} will be, a computer

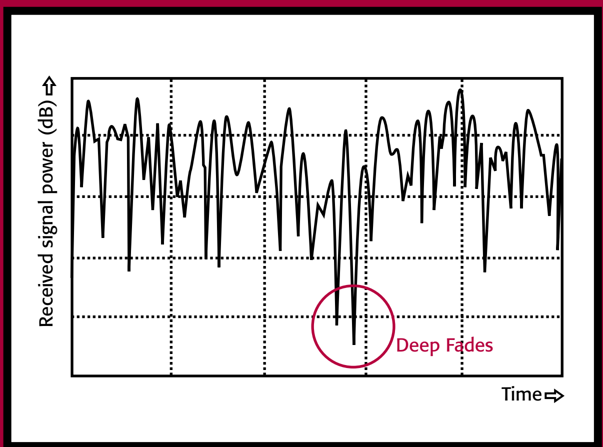

FIG. 2 POWER ENVELOPE OF A TYPICAL FLAT FADE SIGNAL

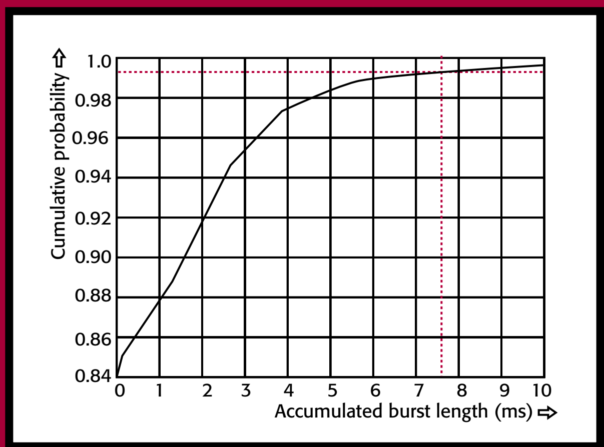

FIG. 3 CUMULATIVE DENSITY FUNCTION OF ACCUMULATED BURST ERROR LENGTH PER TIME INTERVAL

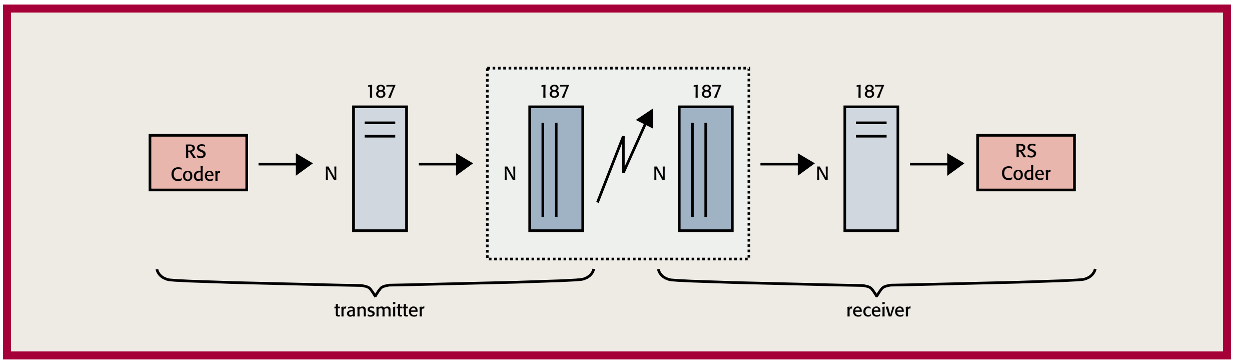

FIG. 4 TIME INTERLEAVING MECHANISM OVERVIEW

simulation of the channel was carried out for the case of a camera operator who walks around in a studio. A typical value for the maximum Doppler frequency in this case is 15Hz, working at a frequency of 2.5GHz. The fading channel can be modelled using a band-limited white Gaussian noise model, which has a Rayleigh probability distribution. A deep fade was assumed to occur every time the envelope of the channel transfer function was more than 20dB below the average value. This results in deep fades occurring about 3% of the time.

In order to estimate a reasonable value for T_{burst}, we have analysed these deep fades. The result of the channel simulation is a probability density function for the length of deep fades, from which a cumulative density function can be derived. This showed only 5% of deep fades that occur are longer than 7.55ms. Therefore the estimate for the interleaving depth needed is:

$$N = \left[7.55 \cdot 10^{-3} \times \frac{187}{188} \times \frac{2.262 \cdot 10^{6}}{23} \right] = 739 \text{ packets,}$$

which corresponds with 739×188 bytes / 2.262×10^6 bytes/s = 61.4×10^{-3} s = 61.4ms.

However, merely looking at the longest deep fades is not the best way to assess the time interleaving performance, as there may be many 61.4ms intervals with no or only a couple of short deep fades. In order to assess the effectiveness of this time interleaving depth, it is therefore more appropriate to consider the length of all burst errors within a time interval of 61.4ms. To this end, the cumulative density function of the length of accumulated burst errors per time interval was calculated (See Figure 3).

We assume the same burst error correction capability per block of 7.55ms. As it has been demonstrated, before time interleaving was applied, signal reception would be error-free for 97% of the time. From Figure 3 can be seen that the system could now handle all burst errors in 99.3% of the time intervals, so this is a significant improvement.

DELAY VS RUGGEDNESS TRADE-OFF

It is clear that time interleaving could be used to make mobile DVB-T microwave links even more rugged. However, time interleaving introduces a significant delay in addition to the video coding delay. Figure 4 shows the memory blocks that are used to modify the order of the data packets. N rows of data are written into a time interleaving block first. As soon as this block is complete, it can be read out in columns. The inverse process takes place in the receiver. Note that the block that is read out column-wise in the transmitter and the block that is filled column-wise in the receiver are separate memory blocks, but the reading and writing takes place simultaneously. Hence, the overall delay introduced by time interleaving (in seconds) is 3×N×187 divided by the DVB-T mode data rate in bytes/s. With N = 739 packets as calculated before and using the same modulation mode, the overall delay is 183 ms.

This is a significant increase compared with a typical video codec delay. It is therefore preferable to use a time interleaver with variable depth. The degree of ruggedness of the system can then be traded off against delay according to the specific application it is used for.

CONCLUSIONS

Time interleaving could make microwave links more rugged in fading channel conditions. The proposed solution should be useful when DVB-T is used in a mobile situation and when it is not possible to avoid flat fading in other ways, such as diversity reception techniques. The benefit of the proposed approach, using an additional Reed-Solomon coding step and a modified transmission order for the data packets before the data is fed to the existing DVB-T modulator, is that standard DVB-T components in the transmission chain can still be used. Reliability can be traded off against additional system delay.

David van Kemenade and John Zubrzycki are with BBC Research & Development. Anton van Roermund is chairman of the Mixed-signal Microelectronics Group at Eindhoven University of Technology