Optimization of the OFDM Interleaving Scheme

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The current draft IEEE OFDM standard specifies a block interleaver where the *i*th interleaved bit at each OFDM symbol is equal to the *k*th encoded input bit, where *k* is given by:

k=8i-(d-1)floor(8i/d) i=0,1,...,d-1

and d is the interleaving depth, which is equal to the number of bits per OFDM symbol, so d=48, 96 or 192 for BPSK, QPSK or 16-QAM, respectively. For instance, for 16-QAM 192 bits per symbol are interleaved as:

0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 104, 112, 120, 128, 136, 144, 152, 160, 168, 176, 184,
1, 9, 17, 25, ..., 185,
....
7, 15, 23,...,191

The interleaver can also be described as a block interleaver with 8 rows and 4*6 columns for 16-QAM, 2*6 columns for QPSK and 6 columns for BPSK. The bits are read in column-wise and read out row-wise.

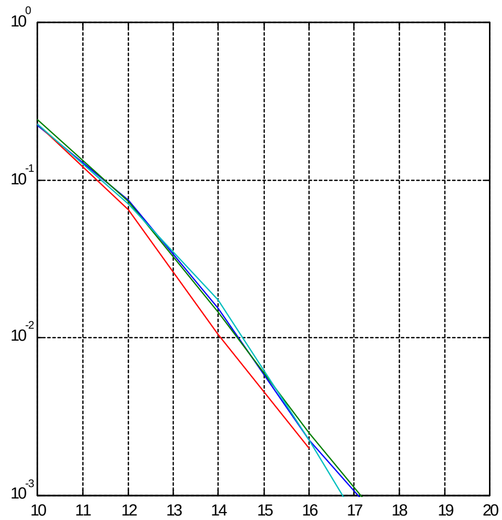
The above interleaver ensures that erroneous bits from one subcarrier are separated by 8 bits after deinterleaving. Further, adjacent bits are separated by 6 subcarriers. These properties help to randomize bursts of errors which otherwise could cause decoding errors. The choice of the number of rows and columns of the interleaver is a tradeoff between separation of bits in the same subcarrier and separation of bits between adjacent subcarriers. Because of multipath fading, some of the subcarriers can have such a low amplitude that the bits in those subcarriers have a high probability of error, so it is desirable to separate those bits as much as possible after deinterleaving to avoid bursts of errors. However, if one subcarrier is in a deep fade, the adjacent subcarriers generally also have low amplitudes, so it is also desirable to separate bits from adjacent subcarriers as much as possible.

For an interleaving step larger than 8, the distance between bits from the same subcarrier is increased, at the cost of a decreased subcarrier distance between adjacent bits. For instance, for an interleaver step of 16, the interleaving order is:

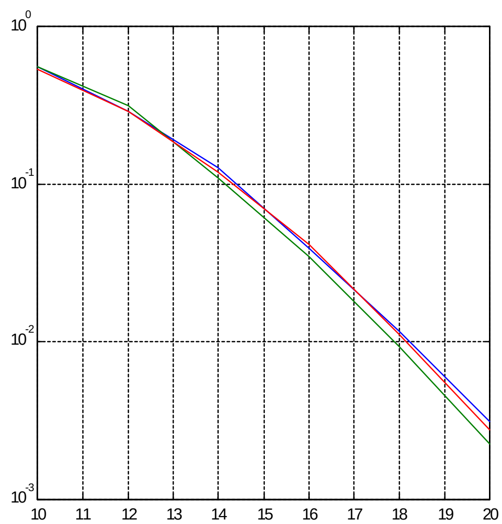
0, 16, 32, 48, 64, 80, 96, 112, 128, 144, 160, 176,
1, 17, 33, ..., 177,
...
15, 31, ..., 191

which defines a block interleaver with 16 rows and 4*3 columns. Erroneous bits from one subcarrier are now separated by 16 bits after deinterleaving, but adjacent bits are only separated by 4 subcarriers. To find out what the best interleaving choice is, simulations have been performed for different interleaving parameters and various rates. All simulations used the standard multipath model with Rayleigh fading paths and an exponentially decaying power-delay profile. The following figures show packet error ratios versus mean E_b/N_o for 64 byte packets with the interleaver step size as a parameter. From these simulations it can be concluded that:

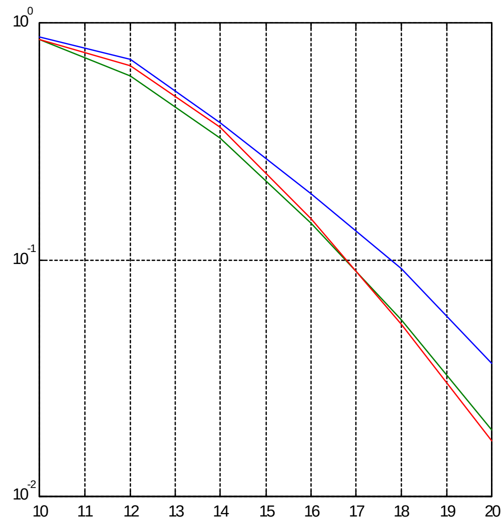
- An interleaver step size of 16 gives the best performance; for large delay spreads up to 200 ns, an SNR gain of more than a dB can be obtained compared to a step size of 8.
- For low delay spreads of 50 ns or less, the difference between various interleaver parameters negligible. This is logical since in the limiting case of a zero delay spread, all subcarriers have the same amplitude, so it does not matter how the bits are interleaved over the different subcarriers.



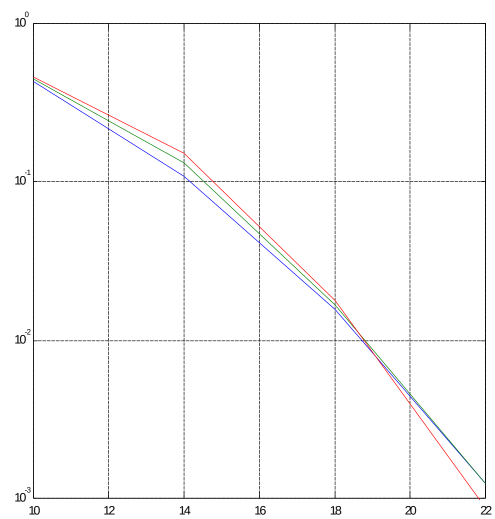
PER versus E_b/N_o for 12 Mbps, 150 ns delay spread, interleaving step = 8 (dark blue), 12 (green), 16 (red), 24 (light blue).



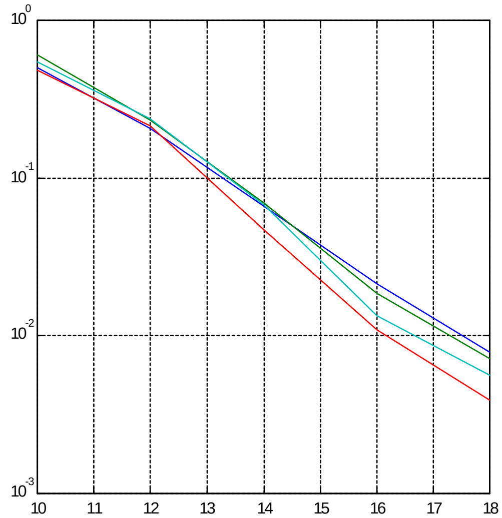
PER versus E_b/N_o for 18 Mbps, 150 ns delay spread, interleaving step = 8 (blue), 16 (green), 24 (red).



PER versus E_b/N_o for 36 Mbps, 150 ns delay spread, interleaving step = 8 (blue), 16 (green), 24 (red).



PER versus E_b/N_o for 24 Mbps, 50 ns delay spread, interleaving step = 8 (blue), 16 (green), 24 (red). This shows that for low delay spreads, the interleaver size is less important.



PER versus E_b/N_o for 24 Mbps, 200 ns delay spread, interleaving step = 8 (dark blue), 12 (green), 16 (red) and 24 (light blue). For this relatively large delay spread, a step size of 16 gains more than 1 dB of SNR for packet error ratios around 0.01.

Conclusion

For the number of rows in the block interleaver, 16 is a better choice than 8. It gives a slight SNR gain in multipath fading channels of up to 1 dB for 200 ns delay spread, and also improves the maximum tolerable delay spread.