Modern Coding Schemes for Unequal Error Protection

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I confirm that this dissertation represents my own work. The contribution of any supervisors and others to the research and to the dissertation was consistent with normal supervisory practice.

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Abstract

In this thesis, we present modern and efficient channel coding techniques for the protection of user data with heterogeneous error sensitivities. Especially multimedia data being transmitted through communication networks often consist of unequally important parts, such as header information, essential payload, and additional data for increased quality. Protecting all data equally makes the transmission inefficient. A system providing unequal error protection (UEP) may be much more efficient and improve the perceptual quality at the receiver.

UEP transmitters and receivers should be designed such that transmission errors only lead to graceful degradation. For good channel conditions, the quality at the receiver is usually good. If the channel conditions degrade, UEP receivers should still be capable of exploiting at least the most important data in order to allow for graceful degradation instead of complete failure.

First, we introduce time-variant, rate-compatible pruned convolutional codes, which are a counterpart of the well-known punctured convolutional codes. Pruning may be an alternative to puncturing, especially if no feedback channel from the receiver to the transmitter is available. Variable-rate code families can be constructed from a given mother code by selectively pruning state transitions in the trellis of the code, thereby reducing the code rate. Theoretically, any code rate smaller than that of the mother code can be generated by applying suitable pruning patterns. We show that the free distance of a convolutional mother code can be specifically increased by pruning and that pruned convolutional codes are automatically rate compatible. Furthermore, we list tables of pruning patterns leading to good decoding results when being applied in convolutional and Turbo codes.

As an additional result, we present an analysis of hybrid code concatenations and their decoder scheduling. Time-invariant pruning can be represented as the serial concatenation of a pruning code and the mother code. Using pruned codes for Turbo codes leads to a hybrid serial/parallel concatenation. The decoding success of such a hybrid concatenation strongly depends on the scheduling of the constituent decoders. We show a detailed analysis of the decoding process and propose an optimisation strategy for successful decoding with a minimum number of necessary iterations.

Another efficient coding scheme is multilevel coding which is a combination of channel coding and modulation, where both are jointly optimised. Multilevel codes are not

restricted to certain types of codes or modulation schemes and are, therefore, very flexible. The theory of multilevel codes provides a very natural and intuitive extension to unequal error protection. We present design rules for such systems based on the optimum design criteria for multilevel codes, i.e., the mutual information. By applying pruned and punctured Turbo codes as channel codes and higher order signal constellations in the modulation unit, we show examples of an image transmission where the UEP design yields good results whereas a standard design is not able to reconstruct the image at the receiver at all. The results and flexibility are further improved by applying special hierarchical modulation schemes instead of standard signal constellations.

The third part of the thesis contains design strategies for bandwidth-efficient low-density parity-check (LDPC) codes providing UEP. An intuitive way of designing UEP-LDPC codes is to design the variable node degree distribution in an irregular way. When dealing with higher order signal constellations, the code bits experience non-uniform disturbances which have to be taken into account during density evolution. We present a hierarchical optimisation algorithm using a detailed density evolution and give a list of optimised degree distributions.

The last part of this thesis is also connected to UEP-LDPC codes and deals with the UEP properties of different construction algorithms for the parity-check matrix of an LDPC code. We experience differences in the UEP behaviour of different construction algorithms despite them producing graphs with exactly the same degree distributions. We discuss several well-known algorithms and analyse properties of the parity-check matrix which are relevant for these different behaviours. For an extensive analysis, we define a detailed check node degree distribution and specify the corresponding detailed mutual information evolution. In order to confirm our argument, we modify a construction algorithm without UEP capability such that the relevant properties are changed and a UEP-capable code is obtained.

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