Markers for Balancing Runlength-Limited Sequences

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Abstract

Binary runlength-limited (RLL) sequences have the property that any run of consecutive zeroes or ones has a length which is lower and upper bounded by certain specified values. Such sequences have found wide-spread applications in digital communication and storage systems [4], particularly in optical recording, e.g., CD, DVD, and Blu-ray. The limits are set according to practical system implementation requirements. For example, in the CD system, any run has a length of at least three and at most eleven, in order to avoid inter-symbol interference and to maintain synchronization, respectively.

Besides satisfying runlength constraints, it may also be desirable that the sequences are balanced, i.e., they contain equally many zeroes and ones. This leads to DC free codes with suppressed low frequency components. An elegant method to balance unconstrained binary sequences has been proposed by Knuth [6]. His algorithm is based on inverting all bits in the sequence beyond a certain index. Knuth showed that there always exists at least one index such that the resulting sequence is balanced. The balancing index is communicated via a (balanced) prefix, allowing the decoder to retrieve the original sequence by inverting the bits beyond the balancing index in the received sequence. In [5], Immink et al. presented an adaptation of this technique in order to balance RLL sequences. As for the original Knuth method, the length of the prefix, and thus the redundancy, grows with the length of the source sequence.

In [1], Ferreira et al. proposed an alternative method for balancing RLL sequences, for which the redundancy does not depend on the length of the source sequence. Hence, for long sequences, this method is more efficient than the one from [5]. The key idea is to communicate Knuth’s balancing index by inserting a marker within the RLL sequence rather than using a prefix. This marker, located at the balancing index, is chosen such that it causes a deliberate violation of the upper runlength constraint. Hence, the decoder can find the balancing index by observing the location of the violation and then retrieve the original RLL sequence after removing the marker. Of course, the marker should be carefully chosen, such that it does not violate the lower runlength constraint and enables unique retrieval of the balancing index. In [3], the principle of a runlength violating marker was applied to keep the running digital sum of a sequence small rather than balancing it. This is an alternative to techniques for improving spectral performance as proposed in [2].

When comparing the methods from [5] and [1], the latter is less redundant and less complex, at the price of an occasional violation of the upper runlength constraint. As argued in [1], such violation is defendable based on technological developments. While the lower runlength constraint is still critical for recording density and reliability, the upper runlength constraint has been relaxed over the years due to improved electronic synchronization circuitry. Using state-of-the-art phase locked loops, occasional violations of the upper runlength constraint are tolerable. However, the simple marker presented in [1] is not optimal, neither from the perspective of minimizing its length, nor from the perspective of minimizing the severeness of the violation. In this lecture, we present optimal markers for each of these two perspectives.

REFERENCES