

Efficient Error Control Schemes for Modulation and Synchronization Codes

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Abstract — We present new methods to protect maximum run-length constrained sequences against random and burst errors and to avoid error propagation. Specific parallel conversion techniques and enumerative coding algorithms for the transformation of binary user information into constrained codewords are proposed. The new schemes are simple and very efficient. The methods can be used for synchronization in communication systems and for modulation coding in magnetic and optical recording systems.

I. INTRODUCTION

Run-length limited (RLL) sequences, also known as (d, k) sequences are characterized by the parameters d and k , indicating the minimum and maximum number of “zeroes” between consecutive “ones” in the binary sequence, respectively. In recording systems the parameter d controls the intersymbol interference and k determines the self-clocking properties of the sequence. We consider maximum run-length limited sequences, where $d = 0$.

The $(0, k)$ sequences are typically composed of codewords of a $(0, k, l, r)$ constrained block code, where l and r denote the maximum number of leading and trailing “zeroes” of every codeword. By choosing $l + r \leq k$, the codewords can be concatenated without violating the global $(0, k)$ constraint. The $(0, k)$ sequences are employed in magnetic and optical recording systems [1, 2]. In digital communication systems frame synchronization [3] is often achieved by converting data information into a $(0, k, k, m)$ constrained sequence of length m , which is prefixed by the sync word $0 \dots 01$ of length $k + 2$ to form a frame. The imposed constraints do not allow the sync word to appear at any other position than at the beginning of each frame [3].

Several $(0, k, l, r)$ codes have been constructed in the past, using look-up tables or simple combinatorial circuitry [1]. These codes typically have a block length $n \leq 9$ and consequently have a low rate. Recently, several new methods have been proposed to efficiently convert data words into codewords of high rate constrained block codes. These algorithms are simple and have a linear complexity. It is therefore feasible to construct $(0, k)$ codes with a code rate of 99% or more of the achievable capacity by using long codewords of several hundreds of bits. The constructed codes are, like the majority of constrained codes, not designed to correct transmission errors. Errors that cause violations of the imposed constraints are detectable, but this is insufficient for reliable error control. Due to the variety of error types, we do not try to combine error control and constrained coding methods. We propose to convert user information into a constrained sequence, preferably by using very high rate constrained codes, and to protect the resulting sequence using systematic error control codes. Special techniques have been developed to add the error control

information, i.e., the parity check bits, without violating the imposed constraints. We propose modulation and error control coding schemes and present enumerative and combinatorial techniques for the analysis and construction of $(0, k, l, r)$ codes with additional constraints to allow error control.

II. CODING STRATEGY

Consider the construction of a $(0, k, l, r)$ code with wordlength n , which is protected by a systematic error control code with e check bits. The main idea is to reserve a set of e fixed positions in the codewords, that are to be filled by the error check bits. In the first stage, all reserved positions, referred to as *unconstrained positions*, are assumed to contain “zeroes” and the user information is encoded and mapped onto the remaining $n - e$ positions of the codeword in such a manner that the codewords still satisfy the imposed $(0, k, l, r)$ constraints. In the second stage, the check bits for the constrained sequence are determined and stored at the reserved positions. The replacement of the “zeroes” by check bits obviously does not violate the imposed constraints.

We present an enumerative coding algorithm for the construction of $(0, k, l, r)$ codes with e unconstrained positions. The code constraints are fulfilled by using position dependent maximum run-length parameters κ_i , the value of which is determined by the constraints (k, l, r) and the number of unconstrained positions around position i , where $1 \leq i \leq n$. The computational complexity of the encoding and decoding algorithms is linear with the wordlength n .

The enumeration technique helps to determine which distribution of unconstrained positions gives the maximal code size, and it is a useful tool for the construction of codes that can be implemented with combinatorial circuitry or small look-up tables.

The proposed error control schemes and coding techniques are very efficient and applicable in communication and recording systems. They can be used in combination with practically any systematic error control code and have several clear advantages with respect to error propagation and achievable code rate relative to the widely used bit-stuffing method and the modulation and error control codes employed in magnetic recording systems.

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