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SHORT COMMUNICATION

The limitation of permutation polynomial interleavers for turbo codes and a scheme for dithering permutation polynomials

Jonghoon Ryu [a], Lucian Trifina [b,*], Horia Balta [c]

[a] Samsung Electronics, Inc., Suwon, Republic of Korea
[b] "Gheorghe Asachi" Technical University, Faculty of Electronics, Telecommunications and Information Technology, Department of Telecommunications, Bd. Carol I, No. 11 A, 700506 Iasi, Romania
[c] University Politehnica of Timisoara, Faculty of Electronics and Telecommunications, Department of Telecommunications, V. Parvan 2, 300223 Timisoara, Romania

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ABSTRACT

In this letter, partial upper bounds on minimum distance for turbo codes with permutation polynomial (PP) based interleavers over integer rings are derived using the fact that PPs are equivalent to a family of linear permutation polynomials (LPPs). It is shown that upper bounds on minimum distance of turbo codes using higher order PP based interleavers are bounded by a function of the number of equivalent LPPs for PPs. Besides, it is shown that when the constant terms of LPPs are dithered, the resulting dithered LPP interleavers perform better than the quadratic permutation polynomial (QPP) based interleavers used in long term evolution (LTE) standard or than other good QPP or cubic permutation polynomial (CPP) based interleavers given in the literature.

1. Introduction

Permutation polynomial (PP) based interleavers over integer rings have been widely studied [1–3,6–8]. In particular quadratic permutation polynomial (QPP) based interleavers were emphasized due to their simple implementation [3] as well as excellent performance [1]. In [1], upper bounds on minimum distance of turbo codes with QPP based interleavers are shown.

Higher order PP based interleavers have also been investigated for better performance and implementation, in particular for cubic permutation polynomial (CPP) based interleavers [2,3]. However little is known for minimum distance of turbo codes with higher order PP based interleavers. In this letter, the technique shown in [3] is used to decompose higher order PPs into linear permutation polynomials (LPPs) and partial upper bounds on the minimum distance for turbo codes using higher order PP based interleavers are shown.

It is also shown that when the constant terms of the LPPs which are equivalent to PPs are dithered, better frame error rate (FER) performance is obtained.

For a more succinct writing, in the following, PP based interleavers are denoted as PP.

* Corresponding author. Tel.: +40 232701679.
E-mail addresses: jonghoon.ryu@samsung.com (J. Ryu), luciant@etti.tuiasi.ro (L. Trifina), horia.balta@upt.ro (H. Balta).

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2. LPP representation of higher order PPs

In this section, previous results on higher order PPs are briefly reviewed and upper bounds on the minimum distance for turbo codes using PPs are shown. Firstly, the equivalence of PPs and a family of LPPs is shown. In the following, a parallel LPP (PLPP) is defined.

Definition 2.1. [3] Let $p(x)$ be an interleaver such that

$$p(x)=\begin{cases} p_0(x)=P_{1,0}x+P_{0,0}, & \mathrm{mod}(x,L)=0\\ p_1(x)=P_{1,1}x+P_{0,1}, & \mathrm{mod}(x,L)=1\\ \cdots & \\ p_{L-1}(x)=P_{1,L-1}x+P_{0,L-1}, & \mathrm{mod}(x,L)=L-1,\end{cases}$$

which can be also represented in the following form,

$$p(x)=\begin{cases} p_0(y)=P_{1,0}\cdot Ly+P\prime_{0,0}, & x=Ly\\ p_1(y)=P_{1,1}\cdot Ly+P\prime_{0,1}, & x=Ly+1\\ \cdots & \\ p_{L-1}(y)=P_{1,L-1}\cdot Ly+P\prime_{0,L-1}, & x=Ly+(L-1),\end{cases}$$

with $1\le L<N$, where N is the interleaver length, $L|N$ and $0\le y\le \frac{N}{L}-1$. Then $p(x)$ is called a PLPP (i.e., $p(x)$ consists of L LPPs).

For each $l=0,1,\cdots,L-1$, $p_l(y)$ is a LPP and since a LPP can be implemented using only additions and comparisons, a PLPP can also

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