

Algebraic-geometric codes from vector bundles and their decoding

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Abstract—Algebraic-geometric codes can be constructed by evaluating a certain set of functions on a set of distinct rational points of an algebraic curve. The set of functions that are evaluated is the linear space of a given divisor or, equivalently, the set of sections of a given line bundle. Using arbitrary rank vector bundles on algebraic curves, we propose a natural generalization of the above construction. Our codes can also be seen as interleaved versions of classical algebraic-geometric codes. We show that the algorithm of Brown, Minder and Shokrollahi can be extended to this new class of codes and it corrects any number of errors up to $t^* = g/2$, where t^* is the designed correction capacity of the code and g is the curve genus.

I. INTRODUCTION

The construction of error correcting codes using methods from algebraic-geometry was first proposed by Goppa [4], [5] in the early '80s. He constructed codes by evaluating a certain set of differential forms on a set of distinct rational points of an algebraic curve. From a dual point of view, Goppa's codes can be constructed by evaluating a certain set of functions on a set of distinct rational points of an algebraic curve [1]. The set of functions that are evaluated is the linear space of a given divisor, whose support is disjoint from the set of evaluation points. These codes generalize the Bose-Chaudhuri-Hocquenghem (BCH), Reed-Solomon (RS) and Goppa codes (latest codes being introduced by Goppa in the early '70s). Unlike the RS codes, algebraic-geometric (AG) codes are not generally MDS codes, but their Singleton defect is upper bounded by the genus of the curve. However, despite their Singleton defect, AG codes are better than RS codes, since they allow the construction of longer codes over the same alphabet. Another advantage of AG codes is that for fixed code parameters, their encoding and decoding algorithms run faster as they can be performed in a smaller field. Since the end of the 80s, intensive research has been done on decoding algorithms and most of the methods used to decode BCH, RS or Goppa codes were extended to the class of AG codes [7].

In order to explain our approach to construct codes from vector bundles on projective curves, let us recall the classical construction of AG codes. Let C be an absolutely irreducible, smooth, projective curve of genus g , defined over a finite base field $\mathbb{F}_q$. Let $P = \{P_1, P_2, \dots, P_n\}$ be a set of distinct rational points of C and $D \in \text{Div}(C)$ be a divisor whose support is disjoint from the set P . The linear code $C(P, D)$ is defined as the image of the evaluation map:

$$\begin{aligned} ev : \mathcal{L}(D) &\longrightarrow \mathbb{F}_q^n \\ f &\longmapsto (f(P_1), f(P_2), \dots, f(P_n)) \end{aligned} \quad (1)$$

where $\mathcal{L}(D)$ is the linear space of D . The parameters of the code, or bound on them, can be determined using well-known statements in algebraic-geometry, notably the Hasse-Weil theorem and the Riemann-Roch theorem, and it can be seen that the Singleton defect of the code is upper bounded by the curve genus g .

Interleaved AG codes were defined in [3] as follows. Suppose that $Q = q^r$ and identify $\mathbb{F}_Q$ and $\mathbb{F}_q^r$ as $\mathbb{F}_q$ -vector spaces by fixing a basis of $\mathbb{F}_Q$ over $\mathbb{F}_q$. For any point $P \in C$ and any $f = (f_1, f_2, \dots, f_r) \in \mathcal{L}(D)^{\oplus r}$, the evaluation vector $f(P) = (f_1(P), f_2(P), \dots, f_r(P)) \in \mathbb{F}_q^r$ can be identified with an element of $\mathbb{F}_Q$. The code $C(P, D, r)$ is defined as the image of the evaluation map:

$$\begin{aligned} ev : \mathcal{L}(D)^{\oplus r} &\longrightarrow \mathbb{F}_Q^n \\ f &\longmapsto (f(P_1), f(P_2), \dots, f(P_n)) \end{aligned} \quad (2)$$

This code does not generally lie in $\mathbb{F}_Q$, however it is a $\mathbb{F}_q$ -vector subspace of $\mathbb{F}_Q^n$.

To explain our approach, we first remark that there is a one-to-one correspondence between the divisor class group $\text{Cl}(C)$ (the group of equivalence classes of $\text{Div}(C)$) and isomorphism classes of line bundles on C . For any divisor D , we denote by $\mathcal{O}(D)$ the line bundle associated with D . The linear space $\mathcal{L}(D)$ is isomorphic to the space of global sections of $\mathcal{O}(D)$, which is generally denoted by $H^0(C, \mathcal{O}(D))$.

We construct AG codes by evaluating global sections of arbitrary rank vector bundles E on the points $P_1, P_2, \dots, P_n$. Thus, the classical construction of AG codes (1) corresponds to the case $E = \mathcal{O}(D)$ and the construction of interleaved AG codes (2) corresponds to $E = \mathcal{O}(D)^{\oplus r}$. In general, if E is a rank- r vector bundle, we obtain a code $C(P, E)$ over $\mathbb{F}_Q$, not necessarily linear, where $Q = q^r$. Further, we investigate the parameters of these codes, or bound on them, such as the code length, dimension, and minimum distance. While the code dimension can still be lower bounded by the Riemann-Roch theorem, it is much harder to compute its exact value or to give a lower bound on the minimum distance. The main reason is that unlike line vector bundles, arbitrary rank vector bundles of negative degree may have non zero sections. To overcome such situations, we need the vector bundle to satisfy some stability condition. When this condition is satisfied, we can compute the code dimension and we can show that the Singleton defect is upper bounded by the curve genus g .

Now we come to the decoding problem. Bleichenbacher, Klavias and Yung [2] proposed a new decoding algorithm for interleaved Reed-Solomon codes over the Q -ary symmetric channel, which was later extended by Brown, Minder and

Algebraic Geometric Codes

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photographs of Mars amongst others We will present some essentials of the theory in this book Using linear algebra we have the salient Hamming codes The next level of coding theory is through the usage of ring theory especially polynomials rational functions and power series to produce BCH codes Reed Solomon codes and the classical Goppa codes Then we progress to the geometric Goppa code using Algebraic Geometry

Coding Theory and Algebraic Geometry Henning Stichtenoth, Michael A. Tsfasman, 2006-11-15 About ten years ago V D Goppa found a surprising connection between the theory of algebraic curves over a finite field and error correcting codes The aim of the meeting Algebraic Geometry and Coding Theory was to give a survey on the present state of research in this field and related topics The proceedings contain research papers on several aspects of the theory among them Codes constructed from special curves and from higher dimensional varieties Decoding of algebraic geometric codes Trace codes Exponential sums Fast multiplication in finite fields Asymptotic number of points on algebraic curves Sphere packings

Introduction to Coding Theory and Algebraic Geometry J. van Lint, G. van der Geer, 2012-12-06 These notes are based on lectures given in the seminar on Coding Theory and Algebraic Geometry held at Schloss Mickeln Diisseldorf November 16-21 1987 In 1982 Tsfasman Vladut and Zink using algebraic geometry and ideas of Goppa constructed a sequence of codes that exceed the Gilbert Varshamov bound The result was considered sensational Furthermore it was surprising to see these unrelated areas of mathematics collaborating The aim of this course is to give an introduction to coding theory and to sketch the ideas of algebraic geometry that led to the new result Finally a number of applications of these methods of algebraic geometry to coding theory are given Since this is a new area there are presently no references where one can find a more extensive treatment of all the material However both for algebraic geometry and for coding theory excellent textbooks are available The combination of the two subjects can only be found in a number of survey papers A book by C Moreno with a complete treatment of this area is in preparation We hope that these notes will stimulate further research and collaboration of algebraic geometers and coding theorists G van der Geer J H van Lint Introduction to Coding Theory and Algebraic Geometry Part I Coding Theory Jacobus H van Lint 11.1 Finite fields In this chapter we collect without proof the facts from the theory of finite fields that we shall need in this course

Algebraic Geometry Codes Michael A. Tsfasman, 2014-05-21 This book is devoted to the theory of algebraic geometric codes a subject formed on the border of several domains of mathematics On one side there are such classical areas as algebraic geometry and number theory on the other information transmission theory combinatorics finite geometries and dense packings

Algebraic Geometric Codes Michail A. Tsfasman, Serge G. Vlăduț, Dmitrij J. Nogin, 2007

Algebraic Geometry in Coding Theory and Cryptography Harald Niederreiter, Chaoping Xing, 2009-09-21 This textbook equips graduate students and advanced undergraduates with the necessary theoretical tools for applying algebraic geometry to information theory and it covers primary applications in coding theory and cryptography Harald Niederreiter and Chaoping Xing provide the first detailed discussion of the interplay between nonsingular projective curves and algebraic function fields

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Algebraic Geometry for Coding Theory and Cryptography Everett W. Howe, Kristin E. Lauter, Judy L. Walker, 2017-11-15

Covering topics in algebraic geometry coding theory and cryptography this volume presents interdisciplinary group research completed for the February 2016 conference at the Institute for Pure and Applied Mathematics IPAM in cooperation with the Association for Women in Mathematics AWM The conference gathered research communities across disciplines to share ideas and problems in their fields and formed small research groups made up of graduate students postdoctoral researchers junior faculty and group leaders who designed and led the projects Peer reviewed and revised each of this volume's five papers achieves the conference's goal of using algebraic geometry to address a problem in either coding theory or cryptography Proposed variants of the McEliece cryptosystem based on different constructions of codes constructions of locally recoverable codes from algebraic curves and surfaces and algebraic approaches to the multicast network coding problem are only some of the topics covered in this volume Researchers and graduate level students interested in the interactions between algebraic geometry and both coding theory and cryptography will find this volume valuable

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