

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 $\mathbb{F}_Q^n$.

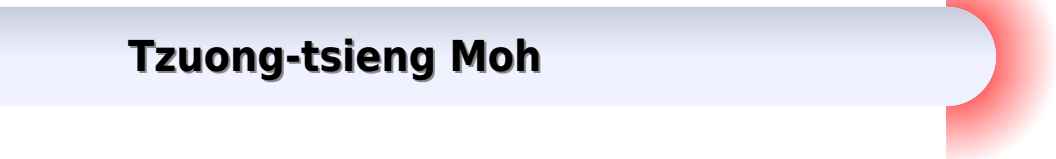
To explain our approach, we first remark that there is a one-to-one correspondence between the divisor class group $\text{Cl}(C)$ (the group of equivalence classes of $\text{Div}(C)$) and isomorphism classes of line bundles on C . For any divisor D , we denote by $\mathcal{O}(D)$ the line bundle associated 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

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