

Channel Coding meets Sequence Design via Machine Learning for Integrated Sensing and Communications

Sundar Aditya, *Member, IEEE*, Morteza Varasteh, *Member, IEEE*, and Bruno Clerckx, *Fellow, IEEE*

Abstract—For integrated sensing and communications, an intriguing question is whether information-bearing channel-coded signals can be reused for sensing – specifically ranging. This question forces the hitherto non-overlapping fields of channel coding (communications) and sequence design (sensing) to intersect by motivating the design of error-correcting codes that have good autocorrelation properties. In this letter, we demonstrate how machine learning (ML) is well-suited for designing such codes, especially for short block lengths. As an example, for rate $1/2$ and block length 32, we show that even an unsophisticated ML code has a bit-error rate performance similar to a Polar code with the same parameters, but with autocorrelation sidelobes 24dB lower. While a length-32 Zadoff-Chu (ZC) sequence has zero autocorrelation sidelobes, there are only 16 such sequences and hence, a $1/2$ code rate cannot be realized by using ZC sequences as codewords. Hence, ML bridges channel coding and sequence design by trading off an ideal autocorrelation function for a large (i.e., rate-dependent) codebook size.

Index Terms—Integrated Sensing and Communications (ISAC), Channel coding, Sequence design, Machine learning-aided Channel coding

I. INTRODUCTION

For communications over unreliable (e.g., noise impaired) channels, the transmitted signal is subjected to channel coding in order to accurately retrieve the intended message at the destination. For ranging (i.e., distance estimation), which is a key component of many radar sensing use cases, it is desirable for the transmitted signal to have an *ideal* autocorrelation function (i.e., equal to $\delta[\cdot]$). These requirements have led to the development of two very rich fields, namely,

- *Coding Theory*, which has resulted in many families of codes (e.g., Reed-Solomon, Polar etc.) with a range of desirable properties from an error-correcting perspective, such as large minimum distance, polarization etc.; and,
- *Sequence Design*, which has resulted in many families of sequences (e.g., Zadoff-Chu (ZC), Golay complementary etc.) that have ideal or near-ideal autocorrelation function

However, in the context of integrated sensing and communications (ISAC), an intriguing question is whether information-bearing channel-coded signals can be reused for ranging,

thereby allowing for efficient resource (time, frequency, power) usage. This forces the fields of channel coding and sequence design to intersect by motivating the design of error-correcting codes that have good autocorrelation properties.

Before exploring the design of such codes, we describe the limitations of two obvious approaches for realizing dual-use ISAC signals:

a) *Using good autocorrelation sequences as error-correcting codewords*: While this approach can be viewed as a special case of index modulation, a feature common to all families of sequences with good autocorrelation properties is the relative scarcity of sequences for a given length N , when compared to the number of possible N -length sequences. This is a direct consequence of striving for an ideal autocorrelation function. As an example, for $N = 32$, the number of ZC sequences (which incidentally have an ideal autocorrelation function) equals 16, which limits the code rate to $(\log_2 16)/32 = 1/8$. A higher code rate cannot be realized as a one-to-one mapping between messages and ZC sequences cannot be constructed.

b) *Using error-correcting codewords as ranging sequences*: Codewords comprising of i.i.d (zero-mean) Gaussian vectors are asymptotically capacity-achieving (over AWGN channels) at large block lengths. Such codewords also have an asymptotically ideal autocorrelation function at large block lengths due to the law of larger numbers (LLN). However, state-of-the-art error-correcting codes are rooted in finite-field algebra, where the codeword symbols post modulation are non-Gaussian and correlated. In [1], it was shown that even such codewords have an asymptotically ideal autocorrelation function at large block lengths (i.e., sidelobes decaying as $O(e^{-rN})$ for code rate r and block length N), regardless of the code's properties such as its generator check matrix. The sidelobe decay is again governed by LLN. For short block lengths though, LLN is not applicable and the sidelobe levels of state-of-the-art error-correcting codewords in this regime are much higher than what can be achieved through sequence design. Hence, we focus on the short block length regime in this letter.

The above limitations clarify the ideal properties that an ISAC error-correcting code must possess in the short block length regime, namely,

- 1) good error-correcting capability,
- 2) large codebook size (equal to 2^{rN} for arbitrary r, N), and
- 3) each codeword must have an ideal autocorrelation function.

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S. Aditya and B. Clerckx are with the Dept. of Electrical and Electronic Engineering, Imperial College London, London SW7 2AZ, U.K. (e-mail: {s.aditya, b.clerckx}@imperial.ac.uk).

M. Varasteh is with the School of Computer Science and Electronic Engineering, University of Essex, Colchester CO4 3SQ, U.K. (email: m.varasteh@essex.ac.uk)

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1. Understanding the eBook Coding Communications And Broadcasting
 - The Rise of Digital Reading Coding Communications And Broadcasting
 - Advantages of eBooks Over Traditional Books
2. Identifying Coding Communications And Broadcasting
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Coding Communications And Broadcasting
 - User-Friendly Interface
4. Exploring eBook Recommendations from Coding Communications And Broadcasting
 - Personalized Recommendations
 - Coding Communications And Broadcasting User Reviews and Ratings
 - Coding Communications And Broadcasting and Bestseller Lists
5. Accessing Coding Communications And Broadcasting Free and Paid eBooks
 - Coding Communications And Broadcasting Public Domain eBooks

- Coding Communications And Broadcasting eBook Subscription Services
- Coding Communications And Broadcasting Budget-Friendly Options
- 6. Navigating Coding Communications And Broadcasting eBook Formats
 - ePub, PDF, MOBI, and More
 - Coding Communications And Broadcasting Compatibility with Devices
 - Coding Communications And Broadcasting Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Coding Communications And Broadcasting
 - Highlighting and Note-Taking Coding Communications And Broadcasting
 - Interactive Elements Coding Communications And Broadcasting
- 8. Staying Engaged with Coding Communications And Broadcasting
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Coding Communications And Broadcasting
- 9. Balancing eBooks and Physical Books Coding Communications And Broadcasting
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Coding Communications And Broadcasting
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Coding Communications And Broadcasting
 - Setting Reading Goals Coding Communications And Broadcasting
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Coding Communications And Broadcasting
 - Fact-Checking eBook Content of Coding Communications And Broadcasting
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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