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Compressing MIMO Channel Submatrices with Tucker Decomposition: Enabling Efficient Storage and Reducing SINR Computation Overhead

Yuanwei Zhang[1], Ya-Nan Zhu[1] and Xiaoqun Zhang[2,*]

[1] *School of Mathematical Sciences, Shanghai Jiao Tong University, Shanghai 200240, P.R. China.*
[2] *School of Mathematical Sciences, MOE-LSC, Institute of Natural Sciences, Shanghai Jiao Tong University, Shanghai 200240, P.R. China.*

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Abstract. Massive multiple-input multiple-output (MIMO) systems employ a large number of antennas to achieve gains in capacity, spectral efficiency, and energy efficiency. However, the large antenna array also incurs substantial storage and computational costs. This paper proposes a novel data compression framework for massive MIMO channel matrices based on tensor Tucker decomposition. To address the substantial storage and computational burdens of massive MIMO systems, we formulate the high-dimensional channel matrices as tensors and propose a novel groupwise Tucker decomposition model. This model efficiently compresses the tensorial channel representations while reducing SINR estimation overhead. We develop an alternating update algorithm and HOSVD-based initialization to compute the core tensors and factor matrices. Extensive simulations demonstrate significant channel storage savings with minimal SINR approximation errors. By exploiting tensor techniques, our approach balances channel compression against SINR computation complexity, providing an efficient means to simultaneously address the storage and computational challenges of massive MIMO.

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Key words: MIMO, SINR, Tucker decomposition, storage reduction, acceleration.

1 Introduction

Multiple-input and multiple-output (MIMO) technology utilizes multiple transmission and receiving antennas to exploit multipath propagation [4, 13]. It has served as the foundation for wireless and mobile networks such as the fourth (4G) and fifth (5G) generations [7,16,28]. Compared with MIMO system, massive MIMO significantly improves

*Corresponding author. *Email address:* xqzhang@sjtu.edu.cn (X. Zhang)

the spectral and transmit power efficiency by equipping hundreds or even thousands of antennas for base station (BS). With a large number of antennas, BSs in massive MIMO system can serve multiples users simultaneously at very low signal-to-interference noise level [6,20,24]. For instance, with a sufficiently large number of antennas, linear precoding methods can achieve performance comparable to that of optimal nonlinear schemes [23]. Moreover, if the number of BS antennas tends to be infinity, the impact of noise and intra-interference will vanish [23]. However, the integration of a large number of antennas in a massive MIMO system also presents unprecedented challenges, particularly in terms of computation and storage.

High computational cost is incurred by signal transmission operations involving large channel matrices. Particularly, numerous operations require computational complexity with a cubic dependence on the channel size [2,31,38]. For example, in this paper we consider the linear minimum mean squared error (MMSE) equalization and singular value decomposition (SVD) precoding method, for achieving an optimal Signal-to-Interference Noise Ratio (SINR) among all linear schemes [34]. This equalization method involves matrix-matrix multiplication and matrix inversion while the precoding method relies on SVD of channel matrices. These operations impose a substantial computational cost on massive MIMO implementations due to the large number of antennas and served users. On the other hand, channel state information (CSI) matrices are necessary for both precoding and equalization. As the number of antennas is significantly larger in massive MIMO than that in traditional MIMO systems, the CSI matrices are considerably larger. As a result, the massive MIMO system requires much higher memory capacity than conventional MIMO systems, often exceeding the size by over 100 times in practical scenarios [22].

Current research usually treats data compression and computational complexity reduction as two distinct objectives. Numerous studies focused on developing efficient and low-complexity algorithms for precoding/equalization. In [3,30,37], truncation techniques were employed to approximate matrix inversion using a Taylor series expansion for achieving complexity reduction. [12] relies on the low-rankness or sparse properties inherent from the system to effectively reduce complexity. Regarding data compression methods, approaches in [10, 27] focused on reducing the size of channel data by converting it into sparse matrices. [19] employs dimensional reduction or compressive sensing techniques for further compression. [21] introduces a technique that entails grouping analogous channel data from antennas and substituting them with average values and representative group patterns.

In this paper, we consider the orthogonal frequency-division multiplexing (OFDM) based massive MIMO systems. Within each channel, the presence of both line-of-sight (LOS) and none-line-of-sight (NLOS) radio waves can be represented as channel submatrices that contribute to channel matrix through linear combinations [1, 31]. Thus, the submatrices within each channel naturally form a 3-order tensor. Research on different tensor decomposition forms has a long history and is continuously evolving. Two well-known tensor decompositions are CANDECOMP/PARAFAC (CP) decomposition [5,11]