On the Performance of LDPC Codes over Radio Stripes System

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Abstract— In the scope of beyond 5G and the forthcoming 6G, Radio Stripes (RS) have been proposed as a potential technique to enhance communications quality for new users. In this paper, we examine the functionality of an RS-aided wireless communication systems, where the transmitted signal is encoded with low-density parity check (LDPC) codes to improve the signal quality. In order to provide high-power, low-latency in 5G communications, LDPC codes, which permit encoding-decoding, have been used. Inter-channel interferences and performances are aimed to be improved with LDPC codes by achieving over 2.5 dB gain, in terms of Bit Error Rate. Using Monte Carlo simulations for various numbers of RS-reflecting elements, we show the validity of the beneficial effect of this type of codes.

1. INTRODUCTION

1.1. Motivation Work

Cell-Free Massive MIMO (Cf m-MIMO) is one of the most important advancements in wireless communications systems in recent years. Due to its excellent spectrum efficiency, beamforming gain, tolerable inter-cell interference, and dependability, it is an essential physical layer technology in B5G (Beyond 5G) and 6G [1]. Without creating cell borders, a group of distributed access points (APs) cooperate to simultaneously serve every user on the network. Each AP required its own fronthaul and power source for the early deployment of cell-free m-MIMO. On the uplink, each AP processes the signals it has received and determines channel estimates. After receiving these estimations, the central processing unit (CPU) combines the signals over numerous front-haul links. Radio stripes (RS), which are appropriate for deployments in crowded environments with many APs, such as stadiums and shopping malls, are one way to establish Cf m-MIMO [2]. The APs are sequentially connected and share the same front-haul and power supply connections in a radio-striped network [3]. A further front haul follows as a result, greatly reducing the amount of cabling. Due to their performance that approaches capacity and their simple iterative decoding, low-density parity check (LDPC) codes are crucial for modern communication systems [4]. The 5G networks will transmit user data using LDPC codes, which provide quick encoding and decoding for high-throughput and low-latency communications. Researchers have already begun looking into RS-assisted wireless systems in order to meet the expanding user requirements of wireless systems in B5G and the forthcoming 6G [5].

1.2. Cell-free MIMO

CF m-MIMO systems use a CPU to connect all APs, allowing them to provide service to all users across the same time-frequency resources [6]. They are an excellent choice for next-generation indoor and hotspot coverage scenarios like smart factories, train stations, small villages, shopping malls, hospitals, subways, college campuses, and stadiums, and can offer faster connections than traditional cellular networks. They can also be made safer by combining them with modern technologies like radio stripes, non-orthogonal multiple-access (NOMA), physical layer security (PLS), reconfigurable intelligent surfaces (RIS), and unmanned aerial vehicles (UAV) [7].

1.3. LDPC Coding Concept

LDPC codes are one of the families of linear block codes. An LDPC code $C(n, m)$ is commonly defined through its parity-check matrix ($\mathbf{H}$). $\mathbf{H}$ contain 0's and few 1's. It has a low density of 1's: $W_r \ll n$ and $W_c \ll m$, where W_r and W_c stand for the quantity of 1s in each row (c-node degree) and column (v-node degree), respectively. The v-nodes and the c-nodes are connected by edges, per matrix $\mathbf{H}$. Each edge between a v-node and a c-node, where variable j is a part of the row

h_i's parity-check equation, implies that $h_{ij} = 1$. The bit values connected to the same c-node must accumulate to zero in order for each of the parity-check equations to be satisfied, which is known as $Hx = 0$ [8]. The encoder determines the syndrome $s = Hx$ for a specific source x and delivers it to the decoder; in this case, the encoder coding rate is m/n, meaning the compression ratio is n: m. The decoder then creates the side information y and using a belief propagation or maximum likelihood decoding algorithm, it tries to reconstruct the source x with the aid of a correlation noise model between x and y [9].

1.4. Contribution, and Organization

Previous research published a comprehensive analysis in which LIS is integrated with the LDPC-coded, SC-FDE, and numerous receivers with varying levels of complexity and performance, and then analyzed in various 5G scenarios. In this investigation, four receivers are used: ZF, MMSE, MRC, and EGC. It is demonstrated that when paired with LIS, the use of LDPC-coded can be used with a low degree of complexity when the MRC receiver is used, whose performance in different scenarios is extremely near to the ZF receiver (which has much higher computational requirements).

This article is organized as follows: Section 2 describes the system characterization for cell-free m-MIMO using SC-FDE transmissions; Section 3 analyzes the performance results; and Section 4 concludes the article.

2. SYSTEM MODEL

A cell-free m-MIMO radio stripe network is taken into consideration and is made up of N antennas on each of M APs. The connections for the front-haul come from AP_1, AP_2, ..., AP_M. The CPU is installed, as indicated in Fig. 1. The CPU is situated at the end of the stripe AP_M. L single antenna user equipment's (UEs) are randomly scattered throughout the network, and the channel between $AP_m \in \{AP_1, \ldots AP_M\}$ and lth UE is indicated by the notation h_{lm}. We take into account the coherence block length of the channel τ_c, which is used in the block fading channel model. Each of these blocks involves the drawing of an independent realization as $h_{lm} \sim CN(0, R_{lm})$, from a correlated Rayleigh fading distribution [10]. R_{lm} denotes the spatial covariance matrix, which describes the features of the channel spatial correlation. $\beta_{lm}@tr(R_{lm})/N$ provides the large-scale fading coefficient that describes the shadowing and path loss. It is assumed that the spatial covariance matrices $\{R_{lm}\}$ are known. The τ_p channel is utilized for pilot transmission to estimate the channel, and the $\tau_c - \tau_p$ channel is used for payload data. In this paper we consider the uplink direction [11].

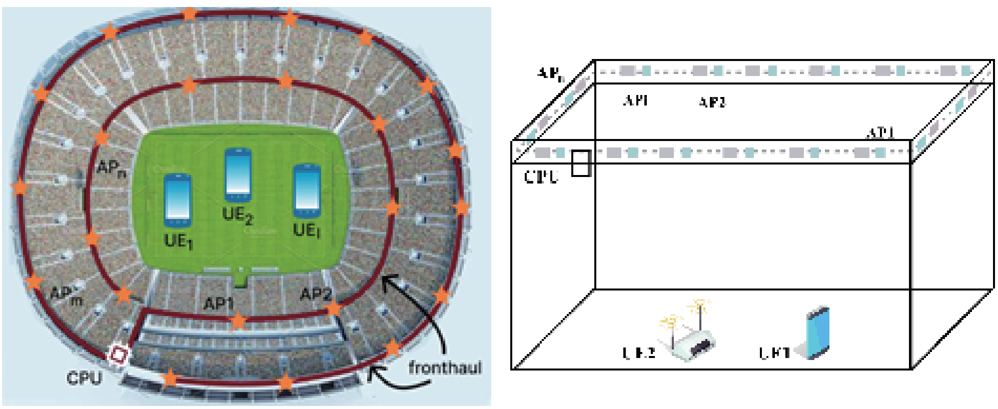

Figure 1. A radio stripe installed along the studium and walls [2].

2.1. Receiver Design

Let X_m denote the signal transmitted by UE_i. Y_m is defined as received signal at AP_m.

$$Y_m = H_m X_m + N_m \tag{1}$$

Here H_m represents the channel matrix.

Different receiver design methodologies are conceivable in RS system settings, such as ZF, MMSE, MRC, and EGC are FDE receivers. The ZF and MMSE algorithms, which require matrix inversions, are unquestionably harmful in this kind of system even though their Bit Error Rate

(BER) results can be wonderful because the computational expense skyrockets with the quantity of transmitting and receiving antennas. The MRC and EGC procedures, on the other hand, are straightforward, which results in less processing and, as a result, energy savings [9].

In (7), B_m denotes the $L \times M$ precoding matrix, and X_m show the data symbols and Y_m is the augmented received signal at AP_m. Depending on the algorithm employed, the precoding matrix B_m can be computed as follows [12]:

$$B_m = \begin{cases} H_m \left(H^H H_m\right)^{-1} & \text{for ZF} \\ H_m \left(H^H H_m + \beta I\right)^{-1} & \text{for MMSE} \\ H_m & \text{for MRC} \\ \exp\left\{jArg\left(H_m^H\right)\right\} & \text{for EGC} \end{cases} \tag{2}$$

$$\beta = \frac{E\left\{|N_m|^2\right\}}{E\left\{\left|\hat{X}_m\right|^2\right\}} = \frac{\sigma_N^2}{\sigma_{\hat{X}}^2} \tag{3}$$

We could use MRT or EGT at each frequency, based on $H_m B_m$, to perform frequency-domain processing on SC-FDE signals. The residual interference levels, however, can still be significant, particularly for modest values of M/L. The iterative interference canceller (receiver) is what we suggest as a solution to this issue [12].

$$\hat{X}_m = Y_m - C_m \bar{X}_m \tag{4}$$

When I is an $M \times M$ identity matrix, then

$$C_m = H_m B_m - I \tag{5}$$

defines the interference cancellation matrix C_m.

3. SIMULATION RESULTS

This section examines the BER performance from RS systems, computed using based Monte Carlo simulations for SC-FDE block transmission method and LDPC codes. N_o is the one-sided power spectral density of the noise, and E_b is the energy of the transmitted bits. E_b/N_o is used in the calculation of the BER. For the QPSK modulation, a block size of $N = 256$ symbols was used (similar outcomes were seen for other values of N, provided that $N \gg 1$). LDPC codes of 32400 bytes were considered, with a code rate of 1/2.

The antenna elements of the RS system are spaced apart by a factor of $\lambda/2$. The aforementioned beam can be produced thanks to the channel correlation between the antenna parts. In the Monte Carlo simulation, five statistically independent equal power pathways were taken into account to translate an extreme Rayleigh fading channel. The MRC and EGC receivers do not compute the channel matrix inverse for each frequency component, while the ZF and MMSE do, translating in high processing requirements. The MRC and EGC are less computationally demanding. Last but not least, it should be noted that the EGC tends to perform the poorest.

A list of the baseline simulations used in the various simulations is shown in Table 1.

Table 1. Table type styles.

Figure	**Number of Antennas**	**Number of Users**	**LDPC**	**Objective**
2	50	3	On/OFF	Verify the gain obtained with LDPC codes
3	100	6	On/OFF	Verify the gain obtained with LDPC codes
4	200	12	On/OFF	Verify the gain obtained with LDPC codes

Figure 2 displays the simulation results for the RS System with 3 users and 50 antennas, both with and without LDPC codes. MRC, EGC, MMSE, and ZF are the four examined receivers. Considering these findings, we see that the use of LDPC codes resulted in a performance improvement of the order of 2.5 dB for all receiver types. Also, it is apparent that the MMSE receiver, which is near to the MFB, obtains the best overall performance. Nevertheless, it is achieved at the expense of a greater complexity. The MRC and EGC are less computational demanding than the ZF and MMSE because they do not require the inversion of the channel matrix for each frequency component of the channel.

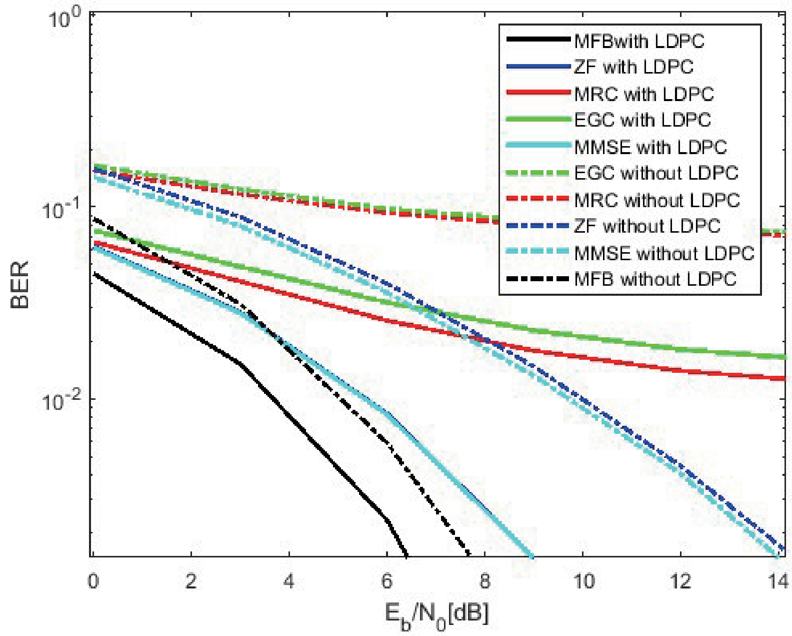

Figure 2. Results for RS System, with 3 users and 50 antennas, with /without LDPC codes.

Figure 3 displays the simulation results for the RS System with 6 users and 100 antennas, both with and without LDPC codes. It is viewed that, by using LDPC codes, a performance improvement of the order of 1 dB is achieved, as compared to the equivalent uncoded scheme.

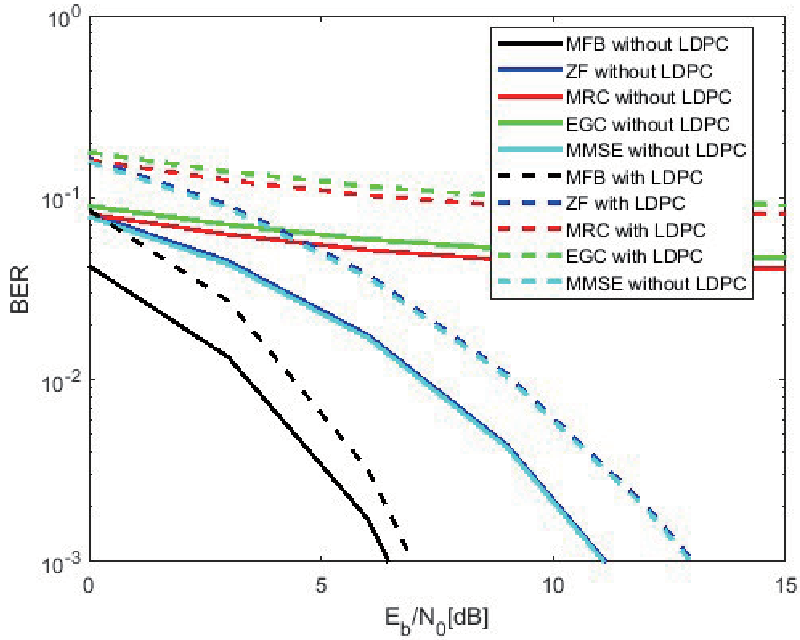

Figure 3. Results for RS System, with 6 users and 100 antennas, with/without LDPC codes.

Figure 4 displays the simulation results for the RS System with 12 users and 200 antennas, both with and without LDPC codes. It is viewed that, by utilizing LDPC codes, a performance improvement of order of 1 dB is achieved, over the corresponding uncoded scheme.

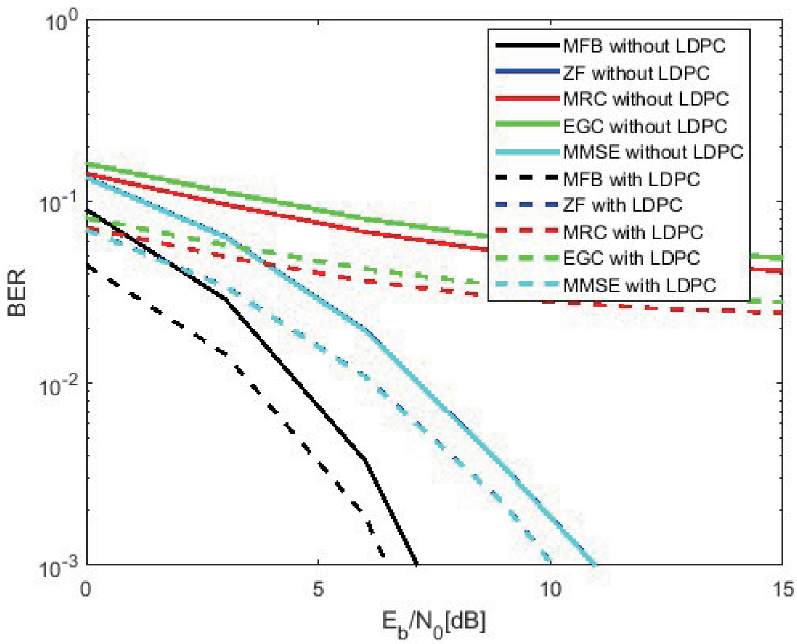

Figure 4. Results for RS System, with 12 users and 200 antennas, with/without LDPC codes.

4. CONCLUSIONS

This paper analysis the performance of the RS system combined with LDPC codes, with several types of receivers: ZF, MMSE, MRC and EGC. Different number of users and various numbers of antennas are considered. It was viewed that the use of LDPC codes always achieve a performance improvement over the uncoded schemes. Moreover, it was viewed that MMSE and ZF are the receivers that achieve the best performance. Nevertheless, these receivers require the inversion of the channel matrix for each frequency component of the channel, while the MRC and EGC receivers do not, being, for this reason, simpler.

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REFERENCES

1. Shaik, H. Z., E. Bjornson, and E. G. Larsson, "Cell-free massive MIMO with radio stripes and sequential uplink processing," *IEEE International Conference on Communications Workshops (ICC Workshops)*, DOI: 10.1109/ICCWorkshops49005.2020.9145164.
2. Kumar, A. and V. Ponnusamy, "Millimeter wave and radio stripe: A prospective wireless technology for 6G and beyond networks," *2021 Smart Technologies, Communication & Robotics (STCR)* Oct. 9–10, 2021, https://doi.org/10.48550/arXiv.2012.11076.
3. Gashtasbi, A., M. M. da Silva, and R. Dinis, "IRS, LIS, and radio stripes-aided wireless communications: A tutorial," *MDPI, Applied Sciences*, Vol. 12, No. 24, 12696, Dec. 2022, https://doi.org/10.3390/app122412696.
4. Fang, Y., G. Bi, L. Y. Guan, and C. M. L. Francis, "A survey on photograph LDPC codes and their applications," *IEEE Communication Surveys & Tutorials*, Vol. 17, No. 4, 2015.
5. López, L. A., D. R. Souza, D. Kumar, P. Popovski, A. Tölli, and M. Latva-aho, "Cell-free massive MIMO with radio stripes for indoor wireless energy transfer," *IEEE Transactions on Wireless Communications*, Vol. 21, No. 9, Sep. 2022.
6. Ma, Y., Z. Yuan, G. Yu, and Y. Chen, "Cooperative scheme for cell-free massive MIMO with radio stripes," *IEEE 2021*, DOI: 10.1109/ICCWorkshops50388.2021.9473493.

7. Elhoushy, S., M. Ibrahim, and V. Hamouda, "Cell-free massive MIMO: A survey," *IEEE Communications Surveys & Tutorials*, Vol. 24, No. 1, First Quarter 2022.
8. Ascenso, J., C. Brites, and F. Pereira, "Design and performance of a novel low-density parity-check code for distributed video coding," *IEEE ICIP*, 2008.
9. Johnson, S. J., "Introducing low-density parity-check codes," Oct. 2015, DOI: 10.13140/RG.2.1.1276.2324.
10. Conceição, F., M. Gomes, V. Silva, R. Dinis, and H. C. Antunes, "Bi-objective power optimization of radio stripe uplink communications," *Electronics*, 11,876, 2022, https://doi.org/10.3390/electronics11060876.
11. Borges, D., P. Carvalho, and F. Dinid, "Low complexity MRC and EGC based Receivers for SC-FDE modulations with massive-MIMO schemes," *Conference Paper*, Dec. 2016.
12. Marques da Silva, M., R. Dinis, and J. Guerreiro, "Implicit pilots for an efficient channel estimation in simplified massive MIMO schemes with precoding," *Hindawi International Journal of Antennas and Propagation*, Vol. 2019, Article ID 5051963, 11 pages, https://doi.org/10.1155/2019/5051963.