On the LIS System Performance with and without Equalization

Ali Gashtasbi[1], **Mário Marques da Silva**[2, 3, 4, 5], **and Rui Dinis**[1, 3, 4]

[1]Faculty of Sciences and Technology, Universidade Nova, Portugal
[2]Universidade Autónoma de Lisboa, Portugal
[3]Autonoma TechLab, Portugal
[4]Instituto de Telecomunicações, Portugal
[5]Ci2 — Centro de Investigação em Cidades Inteligentes, Portugal

Abstract— The Large Intelligent Antenna System (LIS) is a noteworthy development in wireless communications by targeted propagation waves. The LIS idea goes beyond massive MIMO. The LIS consists of a surface that radiates continuously and is made up of a number of small panels that are placed close to the users and can exchange signals. This paper shows the results of a combination of LIS systems with Low-Density Parity-Check (LDPC), comprising Single Carrier with Frequency Domain Equalization (SC-FDE) with four different receiver types: Equal Gain Combining (EGC), Maximum Ratio Combining (MRC), Zero Forcing (ZF), and Minimum Mean Squared Error (MMSE). It is shown that, in the above-described scenario, for some receiver types, equalization can be avoided without degrading performance, while the complexity is reduced.

1. INTRODUCTION

1.1. Motivation Work

Researchers are investigating how new technologies, such as 5G communication technologies and 6G, may be employed in the future. Large intelligent antenna Systems (LIS) have been proposed as a possible candidate technology for future wireless communication systems [1, 2]. This is due to the fact that it would simplify transceiver architecture while also improving service quality [3]. As an extension of massive Multiple Input Multiple Output (MIMO), a LIS system is a surface with a significant number of antennas that may actively send and/or receive data [4]. A LIS establishes a near-field communication that allows, for a certain exact location, high data rates, and a significant number of devices to be linked at the same time [5].

As a promising feature, the LIS can be flexibly implemented in practical communication scenarios [6]. Equipped with a smart controller, the LIS is able to, intelligently, adjust propagation waves to increase the received signal energy, expected to coverage regions, and alleviate interference, therefore, enhancing the communications quality of wireless networks [7, 8]. However, the utilization of LIS in wireless networks also poses a number of unprecedented challenges to the transceiver and LIS design. For example, complexity is a drawback in telecommunications structure.

In this paper, we study the use of a communication system with LIS associated with Low-Density Parity-Check (LDPC) codes. Moreover, we compare several different receivers in terms of performance, which present different complexity levels [9].

The main purpose of channel coding is to make pairs of encoders and decoders that allow reliable communication over noisy channels at information rates that are close to their capacity. The primary impediment to developing practical capacity-achieving codes has been decoding complexity [10]. LDPC codes, on the other hand, have emerged as a class of codes with performance close to the Shannon limit on an Additive White Gaussian Noise (AWGN) channel. Nonetheless, they are well-structured enough to support decoders with circuit implementations. LDPC codes are represented by bipartite graphs, with one set of nodes referred to as a bit node and the other as a check node [11].

1.2. Contribution and Organization

Previous research published a comprehensive analysis in which massive MIMO (m-MIMO) scheme is integrated with the LDPC coded, as well as with Single Carrier with Frequency Domain Equalization (SC-FDE), with various levels of complexity and performance [9]. Such analysis was made in various 5G scenarios. In this paper, four different receivers are used: Equal Gain Combining (EGC), Maximum Ratio Combining (MRC), Zero Forcing (ZF), and Minimum Mean Squared Error (MMSE). It is demonstrated that when the LIS is paired with LDPC-codes, a low degree of complexity is obtained 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 paper is organized as follows: Section 2 describes the system model; Section 3 analyzes the performance results; and Section 4 concludes the article.

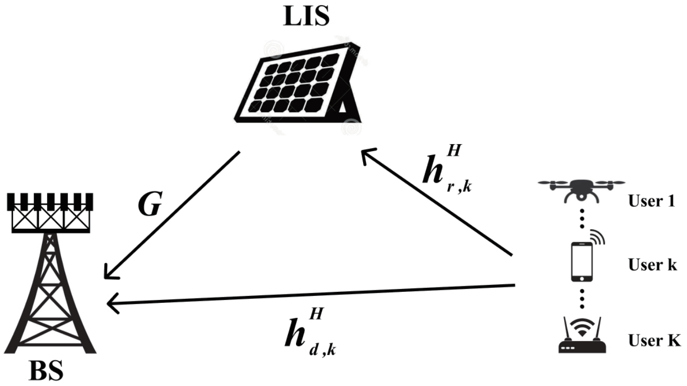

Figure 1. A LIS system installed between a base station and mobile terminals.

2. SYSTEM MODEL

Figure 1 considers the uplink direction of a LIS system, where the link between the Base Station (BS) and the Mobile Terminal (MT) presents two different paths: one direct, and a second through the LIS. In this paper, we focus on the link between the MTs and the LIS system.

This LIS considers a number of P panels, where each panel comprises D antennas (receiving antennas because we consider the uplink). Moreover, the mobile terminal considers a single transmitting antenna. The total number of receiving antennas, from the LIS side, is equal to $R = P \times D$. Moreover, we consider that T MTs transmit simultaneously. This originates a channel of dimension $R \times T$ from the total number of MTs into the LIS system.

2.1. Receiver Design

In LIS system settings, various receiver design methodologies are possible. Frequency Domain Equalization (FDE) receivers include ZF, MMSE, MRC, and EGC. The ZF and MMSE algorithms, which are based on matrix inversions, are unquestionably harmful in this type of system, even though their Bit Error Rate (BER) results can be excellent because the computational cost grows exponentially with the number of transmitting and receiving antennas. In contrast, the MRC and EGC procedures are straightforward, resulting in less processing and, as a result, energy savings [12].

For the evaluation of these various receivers, we need to know about feedback matrices (B_k for feedback matrices).

Using the matrix-vector representation, we can express (1) for LIS structure, using the corresponding frequency-domain block as [13]:

$$Y_k = H_k U_k + W_k \tag{1}$$

where H_k denotes the $R \times T$ channel matrix for the kth frequency. W_k denotes the channel noise.

The combined effect of Inter-Symbol Interference (ISI) and channel noise, the equalized samples S_k, is usually found by optimizing the coefficients B_k under a certain criterion.

$$S_k = B_k Y_k \tag{2}$$

where B_k denotes the $R \times T$ precoding matrix, and the data symbols $X_k = \left[X_k^{(1)}, \ldots, X_k^{(R)}\right]$. Depending on the algorithm employed, the precoding matrix B_k can be computed as [14]:

- ZF employs the Moore-Penrose quasi-inverse matrix technique, also known as the ZF receiver matrix. This approach totally separates the several transmitted data streams by inverting the channel matrix H.

$$B_k = \left(H^H H\right)^{-1} H^H \tag{3}$$

- Employing the MMSE provides estimated signals with the minimum mean squared error.

$$B_k = \left[H^H H + N_o I\right]^{-1} H^H \tag{4}$$

- Using the MRC combines the signals from each branch in order to maximize the received SNR. The inverse of the channel matrix.

$$B_k = H^H \tag{5}$$

- Using the EGC to obtain a high SNR, this equalizer simply uses phase rotations, mixing all received signals with unitary weights.

$$B_k = \exp\left\{j \cdot \arg\left(H^H\right)\right\} \tag{6}$$

For defining the iterative receiver (interference canceller), used by MRC and EGC, we have:

$$\tilde{X}_k = Y_k - C_k \bar{X}_k \tag{7}$$

where the frequency domain estimated data symbols are $\tilde{X}_k = \left[\tilde{X}_k^{(1)}, \ldots, \tilde{X}_k^{(R)}\right]^T$. The interference cancellation matrix can be computed by

$$C_k = H_k B_k - I \tag{8}$$

where I is an $R \times R$ identity matrix.

3. SIMULATION RESULTS

The BER performance results obtained with Monte Carlo simulations, using LIS systems, associated to SC-FDE block transmission technique and LDPC codes. E_b stands for the energy of the transmitted bits, and N_o is the one-sided power spectral density of the noise. The BER is calculated as a function of E_b/N_o. A block size of $N = 256$ symbols was used for the Quadrature Phase Shift Keying (QPSK) modulation (identical results were seen for different values of N, given that $N \gg 1$). LDPC codes, with a code rate of 1/2 and 32400 long, were considered in the simulations. The LIS system comprises several panels, whereas each panel includes several antenna elements. The distance between the antenna elements is $\lambda/2$. The channel correlation between the antenna elements allows for the creation of a beam. Five statistically independent equal power paths were considered in the Monte Carlo simulation to translate for an extreme Rayleigh adding channel.

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

Table 1. List of baseline simulations.

Figure	**Number of Antennas per 4 panels**	**Number of Users**	**Equlization**	**LDPC**	**Objective**
2	25	5	with and without	Off	Absence of performance improvement with the use of equalization
3	25	5	-	On/Off	Performance improvement with LDPC codes, compared to the un-coded system, for 4×25

Figure 2 shows the performance results for 4×25 LIS system (4 panels, each with 25 antennas, making a total of 200 antennas), with 5 users, without LDPC codes, with and without equalization, for the ZF, MRC, EGC, and MMSE, four distinct receivers. Note that only the MRC and EGC may avoid equalization, while ZF and MMSE receivers cannot get rid of equalization. This makes MRC and EGC even simpler, besides the possibility of avoiding the channel matrix inversion for each frequency component of the channel. As can be seen, for the MRC and EGC receivers and 4×25 LIS system, the equalization does not bring any added value in terms of performance improvement, as compared to the results without equalization. Moreover, in this scenario, channel estimation is not required. From these results, we can conclude that the LIS system allows the use of very simple processing, as equalization and channel estimation are avoided, at least for this LIS configuration. Moreover, it is viewed that the MMSE and ZF are the receivers that achieve the best performance, whose curves are almost superimposed. Note that the MMSE and ZF require the channel inversion for each frequency component of the channel, while the MRC and EGC do not require such processing, leading to simple receiver types. Moreover, the MRC performs better than the EGC (whose performance is the worst), but these receivers present a high level of simplicity.

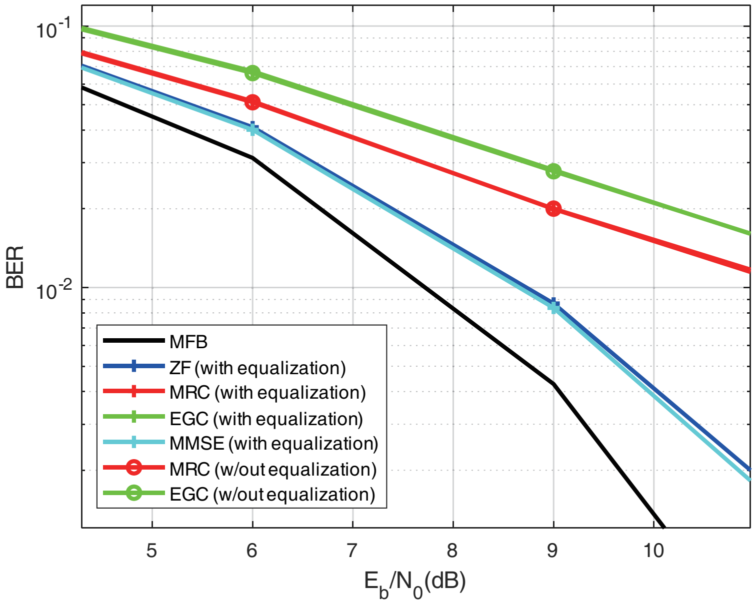

Figure 2. Results for 4×25 LIS System, with 5 users, without LDPC codes, with and without equalization.

Figure 3 displays the performance results for 4×25 LIS System, with 5 users, with and without LDPC codes. With regard to these outcomes, we observe that the use of LDPC codes results in a performance improvement of the order of 3 dB, for all receiver types.

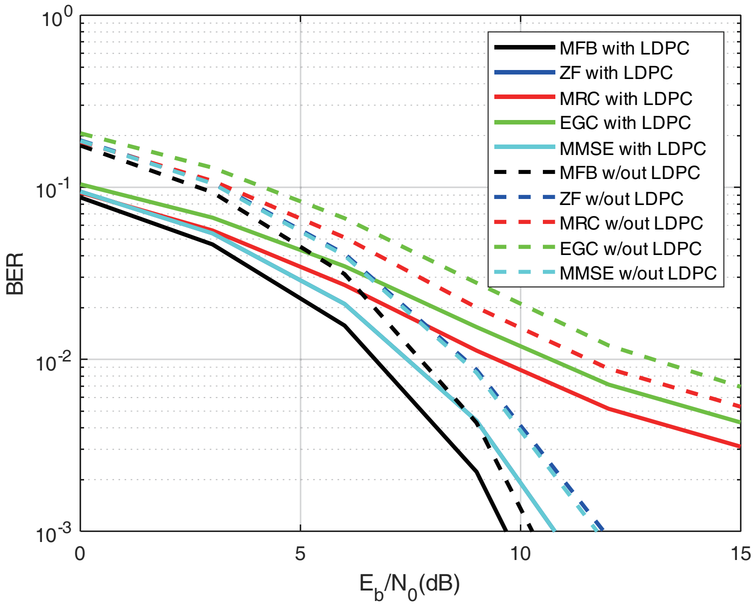

Figure 3. Results for 4×25 LIS System, with 5 users, with and without LDPC codes.

4. CONCLUSIONS

The paper studied the performance of a LIS system combined with LDPC codes and SC-FDE transmission, with several receiver types: ZF, MMSE, MRC and EGC. It was shown that the LIS allows avoiding the use of equalization for the MRC and EGC. Moreover, it was also shown that the MRC and EGC do not require the channel inversion for each frequency component, while the ZF and MMSE do. Moreover, it was viewed that the performance of the MRC approaches that of the MMSE, with a much higher level of simplicity. Finally, it was shown that the use of LDPC codes achieve a performance improvement, for all receiver types, as compared to the uncoded system.

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REFERENCES

1. Lu, L., G. Ye, G. Li, S. Lee, A. Ashikhmin, and R. Zhang, "An overview of massive MIMO: Benefits and challenges," *IEEE Journal of Selected Topics in Signal Processing*, Vol. 8, No. 5, Oct. 2014.
2. Wang, Z., L. Liu, Z. Zhang, and S. Cui, "Massive MIMO communication with intelligent reflecting surface," Jul. 12, 2022, http://arxiv.org/abs/2107.04255v2.
3. Jung, M., Y. Jang, G. Kong, and S. Choi, "Performance analysis of large intelligent surfaces (LISs): Asymptotic data rate and channel hardening effects," arXiv: 1810.05667v4 [*cs.IT*], Dec. 26, 2019.
4. Marques da Silva, M. and R. Dinis, "A simplified massive MIMO implemented with pre or postprocessing," *Physical Communication*, 2017.
5. Hu, S., F. Rusek, and O. Edfors, "The potential of using large antenna arrays on intelligent surfaces," arXiv: 1702.03128v1 [*cs.IT*], Feb. 10, 2017.
6. Gashtasbi, A., M. Marques 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.
7. Yan, W., X. Yuan, and X. Kuai, "Passive beamforming and information transfer via large intelligent surface," *IEEE Wireless Communications Letters*, 2019.
8. Hu, Sh., K. Chitti, F. Rusek, and O. Edfors, "User assignment with distributed large intelligent surface (LIS) systems," *IEEE 29th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2018.
9. Marques da Silva, M., R. Dinis, and G. Martins, "On the performance of LDPC-coded massive MIMO schemes with power-ordered NOMA techniques," *MDPI, Appl. Sci.*, Vol. 11, 8684, 2021, https://doi.org/10.3390/app11188684s.
10. 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
11. Wada, T., "A study on performance of LDPC codes on power line communications," *IEEE Communications Society*, 2004.
12. Hu, Sh., F. Rusek, and O. Edfors, "Beyond massive MIMO: The Potential of data transmission with large intelligent surfaces," *IEEE Transactions on Signal Processing*, Vol. 66, No. 10, May 15, 2018.
13. Pereira, A., P. Bento, M. Gomes, R. Dinis, and V. Silva, "Complexity analysis of FDE receivers for massive MIMO lock transmission systems," *IET Communications*, 2019.
14. Borges, D., P. Montezuma, and R. Dinis, "Low complexity MRC and EGC based receives for SC-FDE modulations with massive MIMO schemes," *GlobalSIP*, 2016.