On the Implementation of Large Intelligent Antenna Systems without Equalization

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Abstract

This paper studies Large Intelligent Systems (LIS) with different receiver types: Equal Gain Combining (EGC), Maximum Ratio Combining (MRC), Zero Forcing (ZF), and Minimum Mean Squared Error (MMSE). We consider Single Carrier with Frequency Domain Equalization (SC-FDE). It is shown that the MRC receiver is much simpler, from the computational point of view than ZF and MMSE, while performing closer to those. Moreover, the MRC avoids the need to perform equalization and, consequently, the need to make channel estimate.

1. Introduction

5G communications were based on Massive MIMO (Multiple Input Multiple Output) and Millimeter Wave Communications. The new requirements expected for 6G communications demand new transmission techniques and spectrum. LIS systems alongside Terahertz bands are expected to be the key issues to achieving such demanding requirements [1].

m-MIMO (Massive MIMO—Multiple Input Multiple Output), UM-MIMO (Ultra Massive-MIMO), and ELAA (Extremely Large Antenna Arrays) are three of the most significant developments in communication system design in recent decades, and they have significantly improved data rate, network capacity, and performance. In this regard, the LIS concept can be viewed as a beyond-massive MIMO in a telecommunications network with increased capacity and data rate, where the number of antennas is even higher.

Traditionally, wireless communications are established in the far-field, that is, with propagation distances beyond the Fraunhofer distance (the Fraunhofer distance is only a few wavelengths). The LIS system comprises several panels, and each panel includes several antenna elements [2,3,4]. As can be seen from Figure 1, the LIS system acts as a near-field beamforming, that is, the communication is established behind the Fraunhofer distance [5,6]. In this case, the individual array elements are in the far-field but not the array as a whole. Consequently, the focus is established not only in the bearing and elevation planes but also in the distance dimension. This allows for the reduction of interferences between users that are aligned but located at different ranges, bringing another advantage, as compared to traditional beamforming [7]. The typical distance between the antenna elements is λ/2. The channel correlation between the antenna elements allows for the creation of the above-described beam.

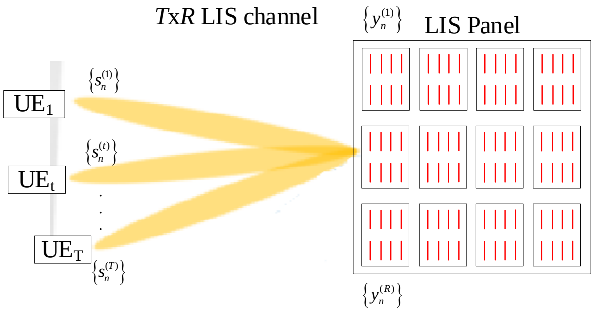

Figure 1 Block diagram of a LIS System

2. System Model

This paper 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.

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 [8].

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 [1]:

$$Y_k = H_k U_k + W_k \tag{2}$$

where H_k denotes the $R \times T$ channel matrix for the k^{th} 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.

$$S_k = B_k Y_k \tag{3}$$

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 [8]:

- 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.

$$B_k = \left(H^H H \right)^{-1} H^H \tag{4}$$

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

$$B_k = \left[H^H H + N_o I \right]^{-1} H^H \tag{5}$$

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

$$B_k = H^H \tag{6}$$

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

$$B_k = \exp\left\{ j \cdot \arg\left(H^H \right) \right\} \tag{7}$$

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

$$\tilde{X}_k = Y_k - C_k \bar{X}_k \tag{8}$$

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

$$C_k = H_k B_k - I \tag{9}$$

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

3. Simulation Results

This section studies the BER performance results obtained with Monte Carlo simulations, using LIS systems, in the Uplink direction, associated with SC-FDE block transmission technique. E_b stands for the energy of the transmitted bits, and N_0 is the one-sided power spectral density of the noise. The BER is calculated as a function of E_b/N_0. A block size of N = 256 symbols was used for the QPSK modulation (identical results were seen for different values of N, given that N >> 1).

The LIS system comprises several panels, whereas each panel includes several antenna elements. The distance between the antenna elements is λ/2. The channel correlation between the antenna elements allows for the creation of the above-described beam. Five statistically independent equal power paths were considered in the Monte Carlo simulation to translate for an extreme Rayleigh fading channel. The simulations considered four receiver types: ZF, MMSE, MRC and EGC.

Figure 2 shows the performance results for 4X25 LIS system (4 panels, each with 25 antennas, making a total of 200 antennas), with 5 users, 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 this. 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 4X25 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, which is very demanding in previous MIMO systems [8]. From these results we can conclude that the LIS system allows the use of a 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. On the other hand, the MRC performs better than the EGC (whose performance is the worst), but these receivers present a high level of simplicity.

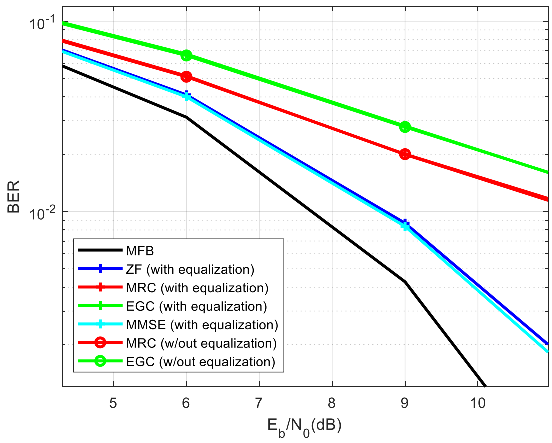

Figure 2. Results for 4X25 LIS System, with 5 users, with and without equalization.

Figure 3 shows the performance results 4X25 versus 4X225 LIS System, with 2 users (1 reference users plus 1 interfering user), for four distinct receivers: the ZF, MRC, EGC, and MMSE, without LDPC codes. As before, the MMSE curve superimpose the ZF one. For all receiver types, the efficiency obtained results with the 4X225 LIS system are better than those achieved with the 4X25 LIS system, as indicated. Nevertheless, it should be mentioned that the MRC, EGC and MMSE are less computational demanding than the ZF. Finally, it should be mentioned that the EGC achieves the worst performance.

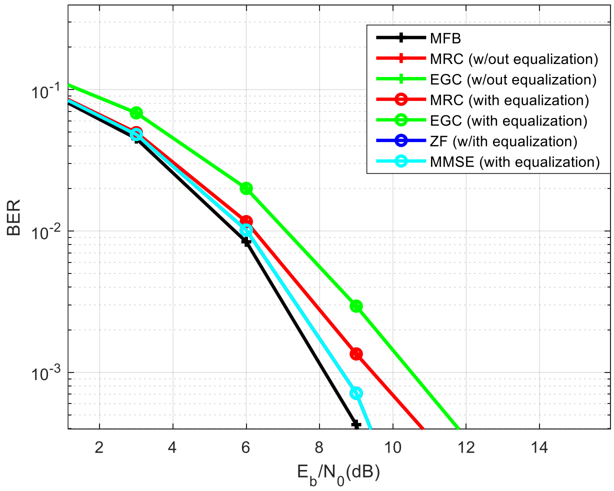

Figure 3. Results for 4X225 LIS System, with 5 users, without LDPC codes, with and without equalization.

4. Conclusions

The paper studied the performance of a LIS system combined with 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. Furthermore, it was 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.

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