LDPC Coding Used in Massive-MIMO Systems

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Abstract. This paper presents the importance of Massive-MIMO systems and the LDPC coding technique used to improve their performance. We will focus on LDPC coding used in the implementation of a Massive-MIMO system and the simulation results using Matlab. A comparison between the classical systems and the LDPC coded system will be made, in order to stress the improvements in particular cases. Starting with simple MIMO systems, the number of antennas at the receiver will be increased and the result will be discussed.

Keywords: Massive-MIMO · Channel coding · LDPC coding Fading

1 Introduction

In the last years, requirements such as increasing the information capacity and throughput in order to support voice applications, video streaming, movies, games, etc., determined the need for increasing and improving the wireless equipment. The necessity of studying Massive-MIMO systems is that they are contained in wireless technologies such as LTE (Long Term Evolution), LTE-A (LTE Advanced), Wi-Fi and make a great point of interest in the future 5G [1, 2]. Regarding these topics, their users are interested in some important aspects like low energy consumption and high transfer rates, while the producers focus on serving as many users as possible without generating any congestion in the system.

In a Massive-MIMO system, a base station contains a large number of antennas (in the same place or spread along its action area) and it serves simultaneously a large number of users within the same time-frequency resource.

The information throughput can be defined as a product between the bandwidth and the spectral efficiency, so if we want to increase the throughput, we have to increase either the bandwidth or the spectral efficiency. The nowadays trend is to increase the last parameter and a very good method of doing this is by using a very large number of antennas for the transmitter and the receiver - which represents the study of Massive-MIMO systems [3].

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2 Massive-MIMO

MIMO (Multiple Input Multiple Output) represents a technology used in radio communications that uses multiple antennas both for the transmitter and for the receiver, for allowing multipath propagation and so the efficient use of the transmission path. Any system can be affected by fading, which seriously affects the signal-to-noise ratio.

Between the transmitter and the receiver, the signal may travel through various paths. By changing the position of the antennas, this path also changes. These paths can produce interferences, but the MIMO technology turns this fact into an advantage by offering robustness to the radio link by increasing the link capacity considering Shannon's law [4].

A MU-MIMO system (Multiuser-MIMO) it is a system where multiple users are simultaneously served by a base station having multiple antennas. Here, a gain is obtained by spatial multiplexing, even if each user has a single antenna [5].

In Massive-MIMO systems, a base station having hundreds of antennas serves ten or more users simultaneously, within the same time-frequency resource. The main advantages of Massive-MIMO are: high spectral efficiency and reliability; energetic efficiency; simplicity of signal processing; interference reducing [6].

It is important to know that these advantages cannot be accessed simultaneously, but according to the application they are used in. By increasing the number of antennas at the base station, the system performance should increase.

The performance of a Massive-MIMO system depends on the characteristics of the transmission and reception antennas but also on the environment where the signals propagate. Theoretically, Massive-MIMO works in a favorable environment, but, in reality, there are cases when the channel in not favorable, for instance the case when the number of paths is smaller than the number of mobile terminals or the case when channels coming from different users share the same path. A possible solution to this problem is placing the antennas of the base station so that they can coordinate a larger area [7].

3 LDPC Channel Coding

For coding Massive-MIMO systems, various techniques can be used, such as turbo codes, LDPC coding and polar coding. The desired channel capacity can be achieved using random codes.

LDPC (Low Density Parity Check) codes are error-correcting codes first used in 1960 at M.I.T. At the beginning, they were considered unpractical, which later turned out to be wrong. LDPC are useful in Massive-MIMO systems, as they have good performance regarding Shannon's limit, which is an important aspect to consider.

LDPC coding consists of creating the parity check matrix [8], H, which has r rows and n columns, which satisfy the relation: $\mathrm{k} = \mathrm{n} - \mathrm{r}$. The element with the ij index is 1 if the j equation contains the i bit, so that the parity check matrix has a small number of ones, which is the reason that these codes are called *low density*. A regular LDPC code has the property that each code bit is contained in the same number of equations and each equation consists of the same number of code symbols.

For LDPC coding and decoding, a representation with graphs is used. The LDPC codes are linear codes obtained from sparse bipartite graphs having n nodes called message nodes and r nodes called check nodes. The property which makes the LDPC algorithms efficient is their sparsity, which means the fact that the occurrence of the 1 element is low. For decoding, LDPC uses message passing algorithms, which are iterative algorithms, being called so because at every iteration, messages are passed from message nodes to check nodes, and from check nodes back to message nodes [9].

For this article we choose to analyze the performance of LDPC in Massive-MIMO systems because the 3GPP standardization group is debating if the turbo code used in 4G should be replaced by the Low Density Parity Check (LDPC) or polar code in 5G. Thus, we are interested to study the performance obtained and the implementation complexity of a multiuser Massive-MIMO system using LDPC codes for the uplink case.

4 Performance of a Massive-MIMO System on the Uplink

For obtaining the following simulations, we started with a MIMO system with a 2 × 2 dimension (2 antennas for the transmitter, 2 antennas for the receiver), analyzing the case with 4 users, for which we have represented the bit error rate (BER) by changing the signal-to-noise ratio (SNR). The fading used has a Rayleigh distribution. We switched between BPSK and QPSK modulation and we used a MMSE detector (Minimum Mean Square Error).

By using BPSK modulation, for a high SNR value, the performance obtained is better than in the case of using QPSK modulation. The results are displayed in Figs. 1 and 2.

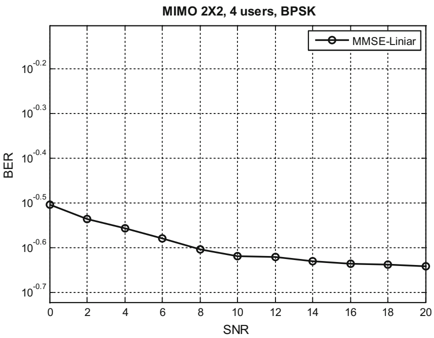

Fig. 1. MIMO system 2 × 2, 4 users, BPSK

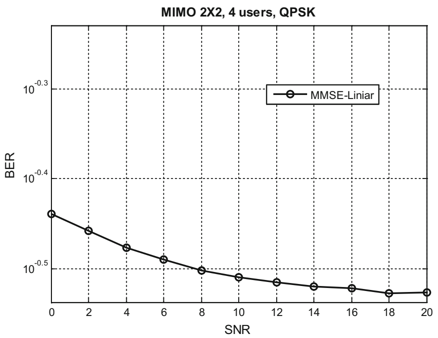

Fig. 2. MIMO system 2 × 2, 4 users, QPSK

It can be noticed that for low SNR values, the performance obtained using BPSK and QPSK is similar: for a SNR = 2 dB, BER is about 0.29 for BPSK and 0.35 for QPSK. By increasing the SNR, for instance, for a SNR = 10 dB, BER = 0.24 for BPSK and BER = 0.31 for QPSK, so the system shows a better performance than the case of a low SNR. For a SNR = 18 dB, BER = 0.22 for BPSK and BER = 0.3 for QPSK.

By increasing the user number from 4 to 10, the performance is similar, as shown in Figs. 3 and 4. A better performance is obtained for high SNR and for BPSK modulation. For a SNR = 2 dB, BER = 0.3655 for BPSK and BER = 0.4055 for QPSK and for SNR = 16 dB, BER = 0.33 for BPSK and BER = 0.38 for QPSK.

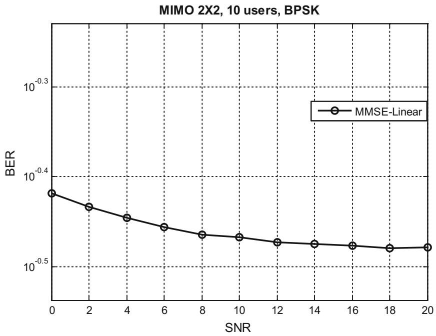

Fig. 3. MIMO system 2 × 2, 10 users, BPSK

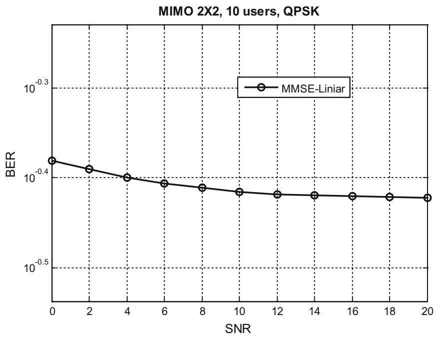

Fig. 4. MIMO system 2 × 2, 10 users, QPSK

The most complex system implemented within this topic it is a system with 2 × . 1 dimension, serving 50 users simultaneously, as shown in Figs. 5 and 6. Here, the performance of using a large number of antennas can be noticed, as the BER decreases from the previous cases: for SNR = 6 dB, in case of BPSK, BER's value goes under 10^{-1}, while for QPSK, it is about 10^{-1}. When the SNR increases, the results are very good, BER $= 5 \cdot 10^{-5}$ for BPSK and BER $= 10^{-3}$ for QPSK, for SNR = 20 dB.

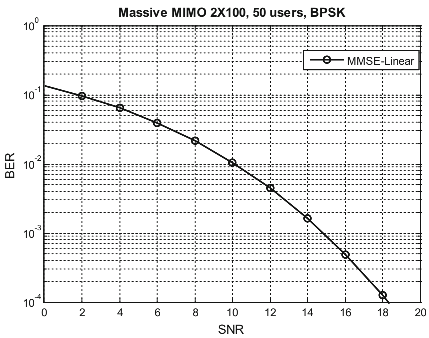

Fig. 5. Massive MIMO system 2 × 100, 50 users, BPSK

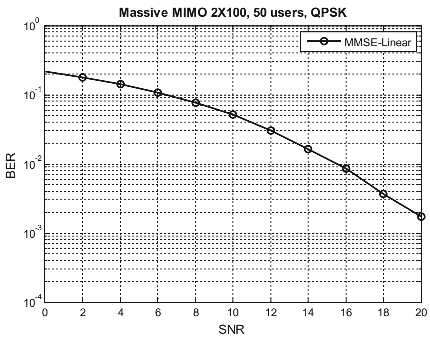

Fig. 6. Massive MIMO system 2 × 100, 50 users, QPSK

In order to analyze the results obtained for using LDPC coding within Massive-MIMO systems, we started with a MIMO system of 2 × 2 dimension which serves 4 users simultaneously. Results are displayed in Figs. 7 and 8. Comparing Figs. 7 and 8 with Figs. 1 and 2 respectively, we can see no improvements in the case of the LDPC coded system and the results are similar for the two types of modulation: BPSK and QPSK (for a SNR = 2 dB, BER = 0.4 for BPSK and BER = 0.36 for QPSK, while for a SNR = 16 dB, BER = 0.34 for BPSK and BER = 0.32 for QPSK).

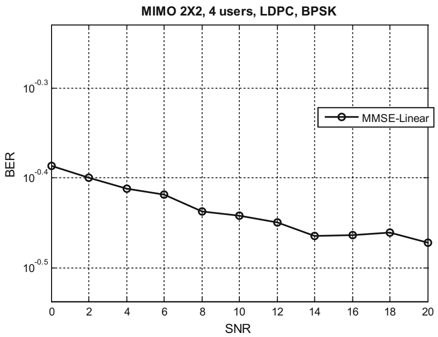

Fig. 7. MIMO system 2 × 2, 4 users, BPSK, LDPC coded

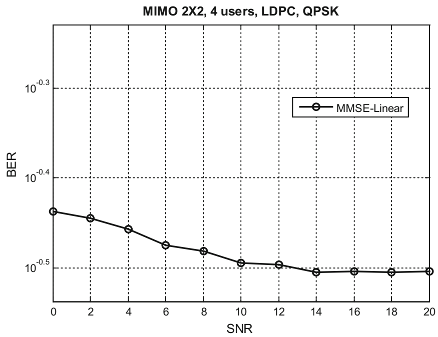

Fig. 8. MIMO system 2 × 2, 4 users, QPSK, LDPC coded

Further on, Figs. 9 and 10 depict the performance for a Massive-MIMO system, LDPC coded, of dimension 2 × 100, serving 50 users simultaneously. This last case shows the best improvements made by using multiple antennas for the receiver, combined with LDPC coding, for which a BER of order of 10^{-6} for BPSK and 10^{-3} for QPSK is obtained, which is a very good result to consider.

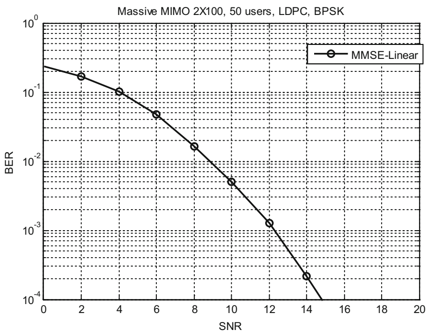

Fig. 9. Massive MIMO system 2 × 100, 50 users, BPSK, LDPC coded

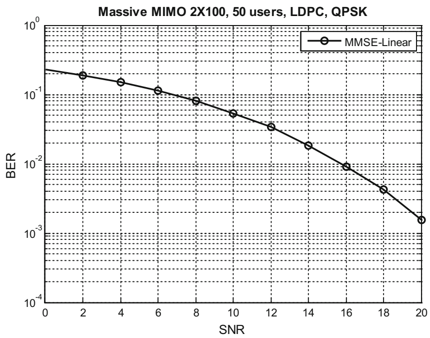

Fig. 10. Massive MIMO system 2 × 100, 50 users, QPSK, LDPC coded

5 Conclusions

In this paper we analyzed the performance of a multiuser Massive MIMO system with LDPC code for the uplink case. We can highlight that the bit error rate decreases as the signal-to-noise ratio increases and has better values for BPSK modulation. BER has a tendency of rising as the number of served users increases. The performance is much better when using more antennas for the receiver, which explains why implementing Massive-MIMO systems in wireless communications. We consider that the results would have been even better if the coding of the source had been done, but we only performed the channel coding which, however, provides good results. Regarding the complexity of the system, which is growing according as the numbers of users and the numbers of antennas at the base station (BS) are increasing. Thus, there should be established a connection between the number of users and the number of BS antennas in order that the performance of the system to be the same for all users whatever is their position in the cell.

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