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IMPROVING THE PERFORMANCE OF LTE TECHNOLOGY BY USING MIMO AND OFDM

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У роботі розглядаються головні аспекти використання в технології LTE систем MIMO та методів ортогональної частотної модуляції. Аналізуються можливості більш повного використання просторового і частотного ресурсів за рахунок адаптивного управління параметрами сигналів у часовій та частотній площинах у залежності від реальних параметрів багатопроменевого каналу зв'язку LTE.

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In this paper we consider the ability to increase the LTE performance using MIMO systems and frequency diversity methods like as OFDMA and SC-FDMA. The effect of using the adaptive modulation in time and frequency domain by taking advantage MIMO and OFDMA and SC-FDMA in LTE technology is investigated.

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В работе рассматриваются различные аспекты использования в технологии LTE систем MIMO и методов ортогональной частотной модуляции. Анализируются возможности более полного использования пространственного и частотного ресурсов за счет адаптивного управления параметрами сигналов во временной и частотной областях в зависимости от реальных параметров многолучевого канала связи LTE.

Introduction

LTE is the brand name for an emerging and fast developing technology that is considered a 4G technology and a big development compared to the existing 3G technologies. Aim for this paper is considering ability of increasing the LTE performance by using MIMO systems and frequency diversity methods like as OFDMA and SC-FDMA. The proposed method for increasing the MIMO and OFDMA in LTE technology depends on the use of adaptive modulation in time and frequency domains, where the used adaptive modulation system in LTE ignores the different fading in different MIMO channels and different frequencies.

I. Analysis of the ability for MIMO systems to improve the performance of LTE communication technology

On the transmitter side of MIMO system the input data stream is divided into M substreams, which are then emitted simultaneously at the same frequency through M transmitting antennas (Fig. 1). In each of the N receiving antennas the signal is under the effect of fading which is added from the mixture of the M transmitted signals from the transmitting antennas and also the additive noise.

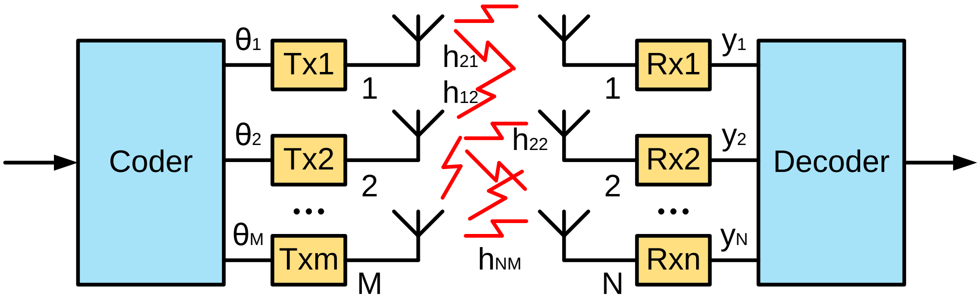


Fig. 1. MIMO system

The signals in the receiving channels can be described by a system of linear equations:

$$\begin{cases} y_1 = h_{11}\theta_1 + h_{12}\theta_2 + ... + h_{1M}\theta_M + \eta_1; \\ y_2 = h_{21}\theta_1 + h_{22}\theta_2 + ... + h_{2M}\theta_M + \eta_2; \\ \\ y_N = h_{N1}\theta_1 + h_{N2}\theta_2 + ... + h_{NM}\theta_M + \eta_N, \end{cases} \quad (1)$$

where y_i count the complex envelope of the *i*-th receiver branch, θ_j – transmitted information symbols through the *j*-th antenna, h_{ij} – complex transfer coefficient between the *j*-th transmitted antenna and the *i*-th received antenna; η_i – count the complex Gaussian noise at the *i*-th input decoder with an average power P_N.

The system of equations (1) can be rewritten in vector-matrix form:

$$Y = H\theta + \eta, \quad (2)$$

where Y – vector of received signals; H – channel matrix; θ – vector transmitted information symbols; η – noise vector. In the mathematical sense, the process of decoding in MIMO system is reduced to solving a system of equations (1) for the unknown θ_j provided that the receiver knows the channel complex factors h_{ij}. As a rule, the transfer of useful information is preceded by phase-smoothing to estimate the characteristics of the channel in the receiver using the pilot signals, resulting in the receiver estimate of the matrix formed by the factors of the channel H [1].

Optimal MIMO scheme with the Feedback (FB). In MIMO system if it's possible to send the channel matrix from the receiver to the transmitter then it is possible to form parallel channels between the transmitter and the receiver and no interference happen between them so it gives the ability to send data through different channels independently. Optimal MIMO scheme with the FB is shown on Fig. 2

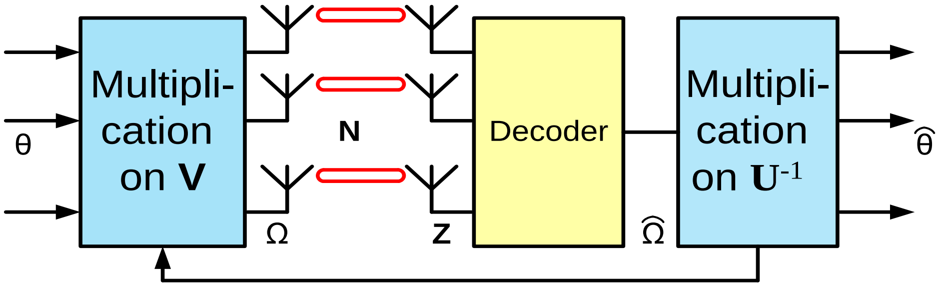


Fig. 2. MIMO scheme with the Feedback

For the formation of optimum directional patterns, it is using singular value decomposition procedure of the channel matrix H [2]

$$H = UDV\,, \tag{3}$$

where U^{-1} and V – unitary matrices that are used to form DP receiving and transmitting sides, respectively; D – diagonal matrix with the eigenvalues of the matrix H in the main diagonal. The equations for the received signal (2) can be rewritten as $H = UDV\theta + \eta$ or $U^{-1}Y = DV\theta + U^{-1}\eta$. Introducing the new notation $Z = U^{-1}Y$ and $\Omega = V\theta$, we obtain the equation of observation in the equivalent system:

$$Z = D\Omega + U^{-1}\eta\,. \tag{4}$$

Thus MIMO channel is described by a diagonal matrix D and can be represented as a set of parallel non-interfering channel SISO [4]. Interference immunity and the capacity of the optimal MIMO systems with FB are much higher than for systems without FB. The availability of data about the channel state information in the transmitter is very important to improve the performance of MIMO, but it's not always possible to implement full transmission of the channel state information through the receiver feedback channel to the transmitter.

Classification schemes of MIMO in LTE. MIMO technologies allow to increase the capacity, operating distance and interference immunity of wireless communications system. To achieve these aims LTE systems provided various schemes for MIMO technology:

– **SU-MIMO** (Single User MIMO): These schemes are designed to improve throughput by multiplexing multiple streams of information in the spatial domain. The transmit and receive paths in the SU-MIMO are shown in Fig. 3. The input data are demultiplexed to K streams (not more than two in LTE Rel. 8), each of which is subject to coding and QAM modulation, formed to K code words. The resulting code words symbols at a time (symbols meant QAM) are distributed between the L levels of spatial multiplexing (SM). Formed vectors of L symbols are multiplied by recoding "for beam-forming" matrix and fed to the M antennas ports *(*$L \le M$*)*.

To support the downlink SM with FB of user station (AS) must transmit over the feedback channel the rank indicator, the channel quality indicator and the pre-coding matrix indicator. With the help of the rank indicator of AS, the numbers of independent spatial channels can be separated at the receiver side of the radio link. If the AS moves at high speed, and the characteristics of the channel change fairly fast, or because the high signaling load on the uplink where it's not possible to pass precoding matrix indicator (PMI), the SM operates without FB.

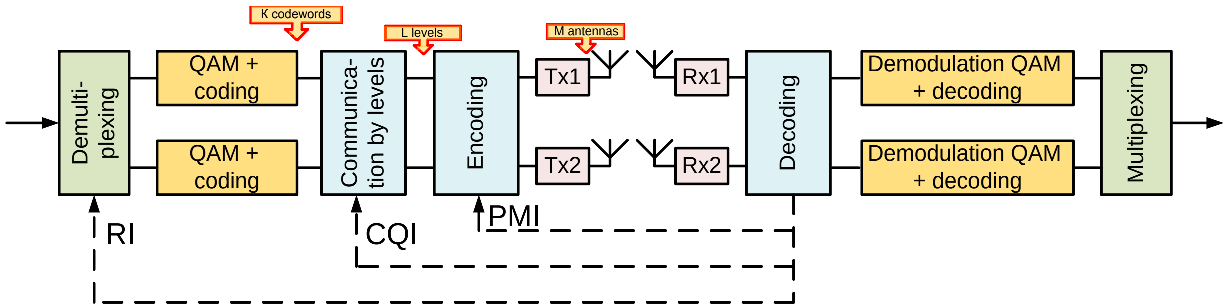


Fig. 3. Transmit and receive paths in the SU-MIMO

– **Transmission diversity.** Downlink transmission is used with Alamouti code [2, 3]. In the basic configuration of this scheme is implemented in a system with two transmitting and one receiving antenna (system 2x1), as shown in Fig. 4.

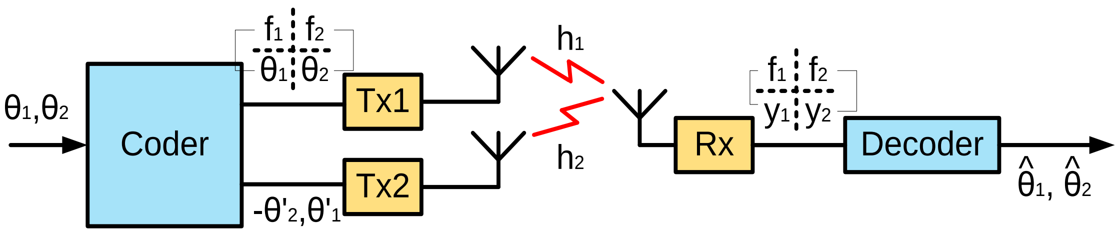


Fig. 4. Transmission diversity

Unlike the original scheme of Alamouti involving spatial and time processing, the LTE uses the space frequency block code (SFBC). In this scheme, modulation symbols of a codeword are divided into blocks of two symbols that are transmitted through two antennas on a pair of adjacent subcarriers. SFBC is described by the generator matrix:

$$\begin{array}{lc} & \begin{array}{cc} f_1 & f_2 \end{array} \\ Antenna\ 1 & \begin{vmatrix} \theta_1 & \theta_2 \\ -\theta_2' & \theta_1' \end{vmatrix} \\ Antenna\ 2 & \end{array}$$

SFBC – orthogonal code generator matrix rows are orthogonal to each other is also true for its columns. SFBC code achieves high interference immunity and it's used primarily to increase the transmit range. Indirect result of using such a scheme to increase the capacity of the system within the cell is possible because it improves the distribution of the signal to noise ratio, and thus it becomes possible to use higher modulation order and that improves the system throughput. To minimize the cost of the equipment's, uplink SFBC does not apply in LTE and the system would use only single antenna, even if there are two antennas in the transmitter and instead of using SFBC the system would use selective transmit technique in order to create the diversity needed to increase the uplink readability. In case of absence of feedback, the AS automatically chooses the antenna to emit signals.

– **MU-MIMO** (Multi User MIMO): the user station located at a sufficient distance from each other can be used to manage its virtual scheme of MIMO, when each of the AS is regarded as a single virtual antenna path. Thus, each spatial level in SM scheme is used for data transfer for one subscriber. Multiuser MIMO scheme can be used for both uplink and downlink. The AS included in the scheme of MU-MIMO, allocated the same frequency-time channel resources. For decorrelation of signals in the channel the system uses the same Transcoder matrix as for SU-MIMO. An example of signal processing scheme's organization on the downlink in the scheme of MU-MIMO with two speakers is shown in Fig. 5.

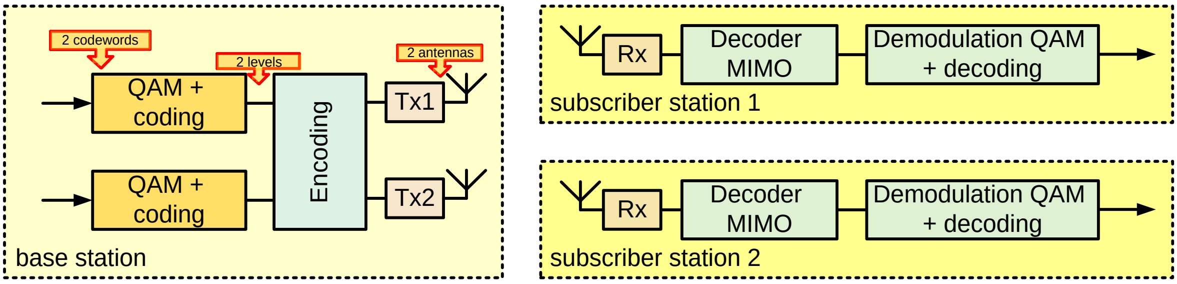


Fig. 5. MU-MIMO

The scheme of MU-MIMO provides spatial diversity of signals for different users. This access method is called (SDMA-Spatial Division Multiple Access).

Although the use of MIMO system with LTE technology increased the performance of the physical layer, our simulation showed that the channels diversity in MIMO is not fully used, and that is because the modulation system in LTE uses the same modulation in different MIMO channels. In [6] it is shown that the use of different modulation types in different channels can lower the BER value. The MIMO model that uses adaptive modulation in different channels is shown in Fig. 6 [6].

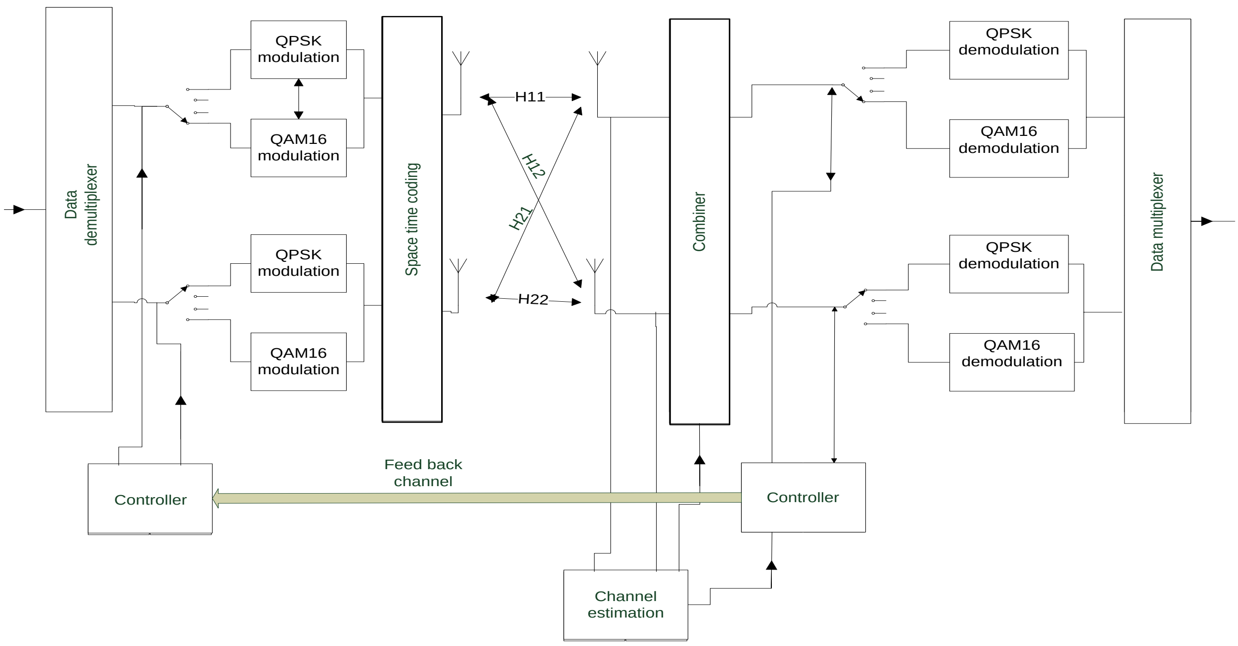


Fig. 6. 2x2 MIMO with adaptive modulation in different channels

II. Analysis of the ability of OFDMA and SC-FDMA systems to improve the performance of LTE communication technology

One of the key elements of increasing the performance of LTE technology with MIMO is the use of OFDM (Orthogonal Frequency Division Multiplex) as the signal bearer and the associated access schemes, OFDMA (Orthogonal Frequency Division Multiplex) and SC-FDMA (Single Frequency Division Multiple Access). In view of its advantages, the use of OFDM and the associated access technologies, OFDMA and SC-FDMA are natural choices for the new LTE cellular standard to decrease frequency selective fading while the MIMO decreases the time selective fading.

The use OFDMA in downlink

The OFDM signal in LTE uses a maximum of 2048 different sub-carriers having a spacing of 15 kHz (Fig. 7). Although it is mandatory for the mobiles to have capability to be able to receive all 2048 sub-carriers, not all need to be transmitted by the base station which only needs to be able to support the transmission of 72 sub-carriers. In this way all mobiles will be able to talk to any base station. Within the OFDM signal it is possible to choose between three types of modulation:

1) QPSK (= 4QAM) 2 bits per symbol.
2) 16QAM 4 bits per symbol.
3) 64QAM 6 bits per symbol.

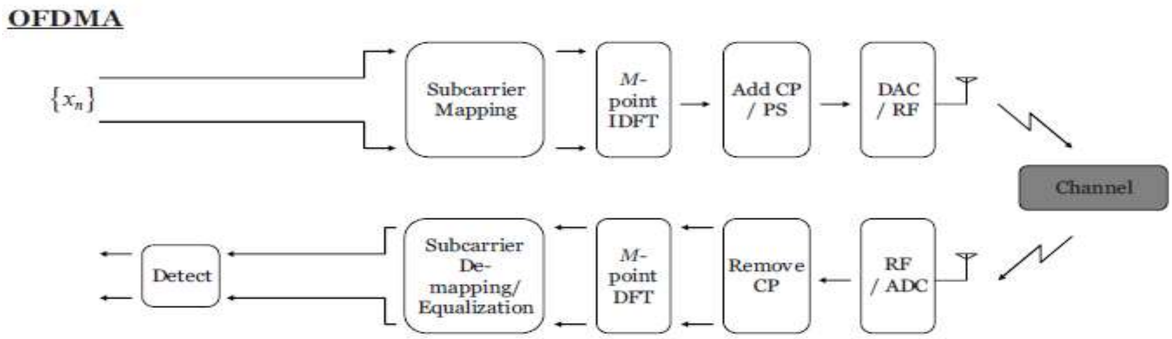


Fig. 7. Transmitter and receiver structure of OFDMA

SC-FDMA (Single Carrier – Frequency Domain Multiple Access)

LTE uplink requirements differ from downlink requirements in several ways. Not surprisingly, power consumption is a key consideration for UE terminals. The high peak-to-average power ratio (PAPR) and related loss of efficiency associated with OFDM signaling are major concerns. As a result, an alternative to OFDM was sought for use in the LTE uplink. (SC-FDMA) is well suited to the LTE uplink requirements. The basic transmitter and receiver architecture is very similar (nearly identical) to OFDMA, and it offers the same degree of multipath protection. Importantly, because the underlying waveform is essentially single-carrier, the PAPR is lower. The block diagram of Fig. 8 shows a basic SC-FDMA transmitter / receiver arrangement.

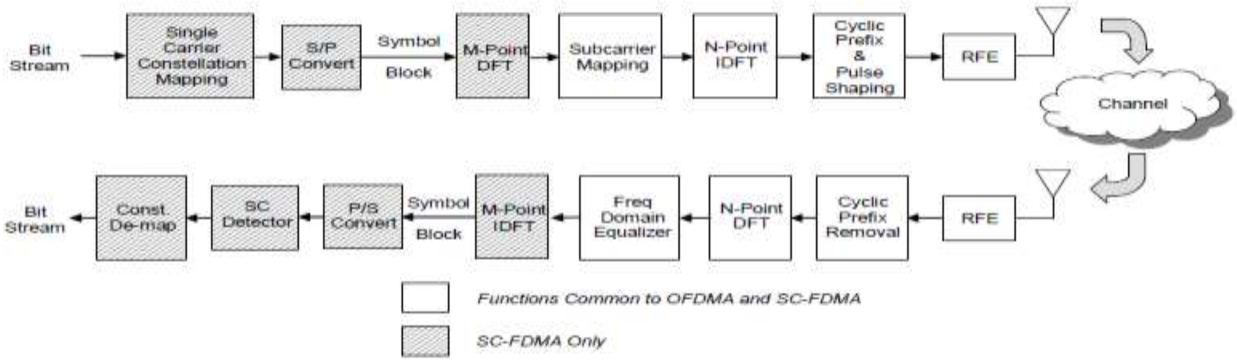


Fig. 8. Transmitter and receiver structure of SC-FDMA

Note that many of the functional blocks are common to both SC-FDMA and OFDMA, thus there is a significant degree of functional commonality between the uplink and downlink signal chains. Unlike OFDM, the underlying SC-FDMA signal represented by the discrete subcarriers is not surprisingly single carrier. This is distinctly different than OFDM because the SC-FDMA subcarriers are not independently modulated. As a result, PAPR is lower than for OFDM transmissions. Analysis has shown that the LTE UE RFPA can be operated about 2 dB closer to 1dB compression point than would otherwise be possible if OFDM were employed on the uplink [5].

As mentioned above, SC-FDMA subcarriers can be mapped in one of two ways: localized or distributed as shown in Fig. 9. Also as we proposed the use of adaptive modulation in different MIMO channels where the fading is time selective, we also can use the adaptive modulation in frequency domain by taking advantage of the use of OFDM with LTE. LTE technology doesn't define the adaptive modulation in frequency domain which can increase the BER performance of OFDM as it is shown in [7].

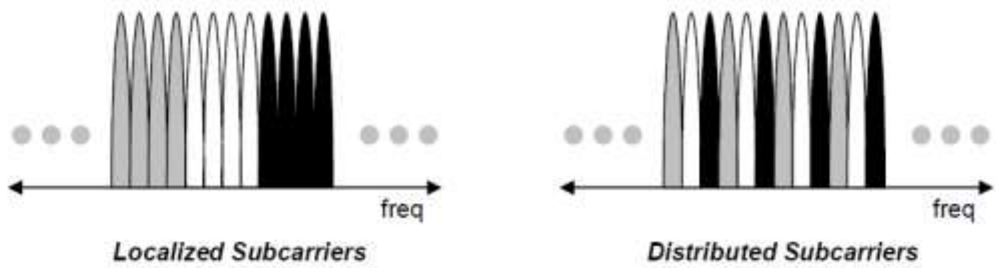
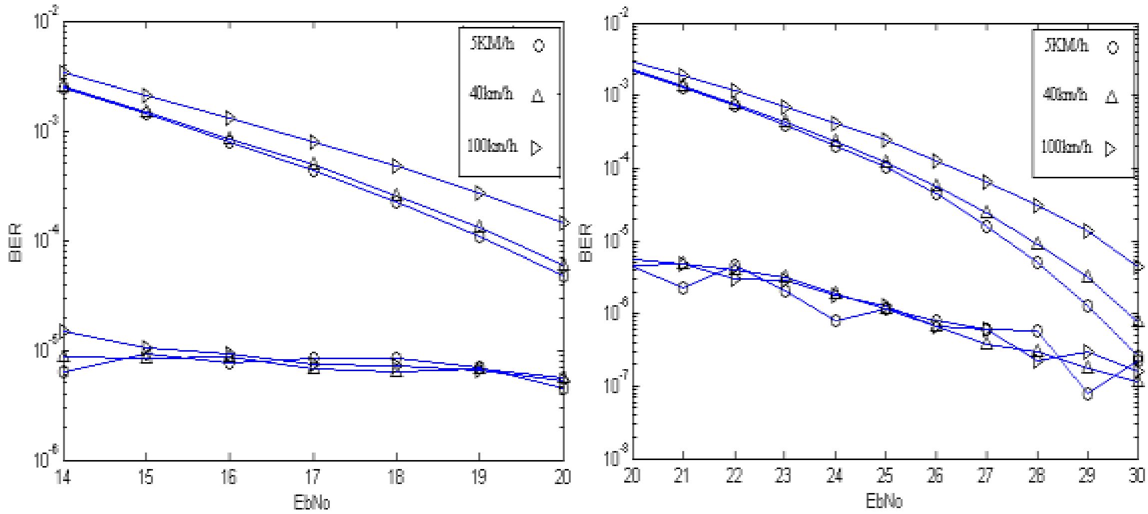


Fig. 9. SC-FDMA Subcarriers Can be Mapped in Either Localized or Distributed Mode

III. Simulation Results

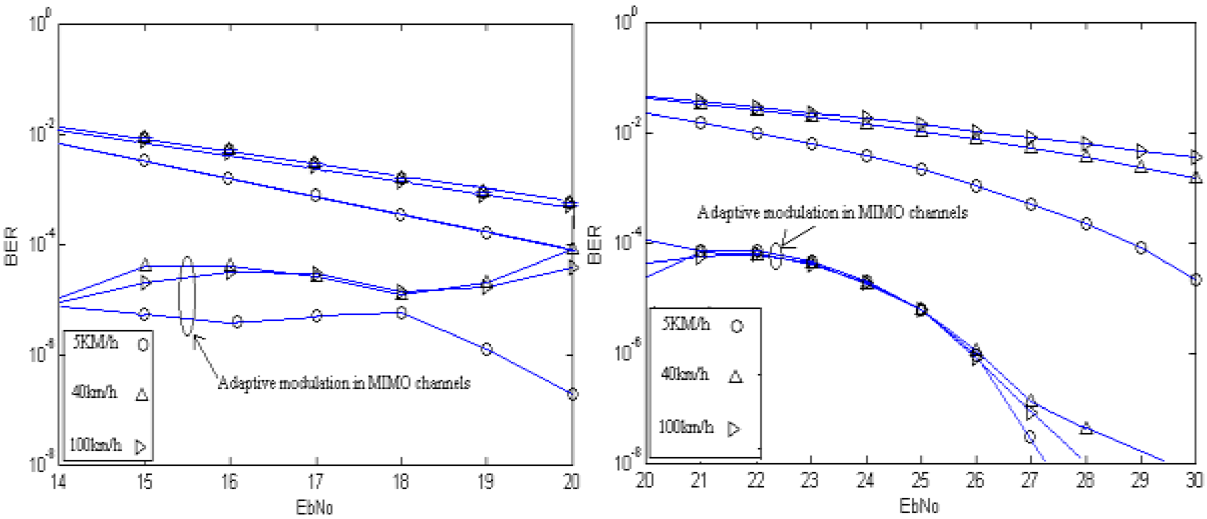
The simulation results for the adaptive modulation for MIMO without feedback are in Fig. 10. In Fig. 10(a) the simulation shows the BER for adaptive modulation in MIMO channels compared to fixed QAM16 with three speeds which are the upper curves. The BER for the three speeds as follows: 5 km/h —20 dB, 40 km/h — 20.2 dB and 100 km/h — 21 dB. The BER for adaptive modulation in MIMO channels is fixed under 10^{-4} for the three speed vales as we see the three lower curves in Fig. 10(a). In Fig. 10(b) we have the same thing but by comparing the adaptive modulation to QAM64, where the three upper curves represent the BER for QAM64 with three speeds, while the lower curves represent adaptive modulation in MIMO channels. The BER results for QAM64 are as follows: 5 km/h — 25 dB, 40 km/h — 25.2 dB and 100 km/h — 26 dB, while the BER for adaptive modulation in MIMO channels is fixed under 10^{-4} for the three speeds.



a) b)

Fig. 10. Bit error rate by using adaptive modulation in MIMO channels and without QAM16 modulation (a) and QAM64 modulation (b)

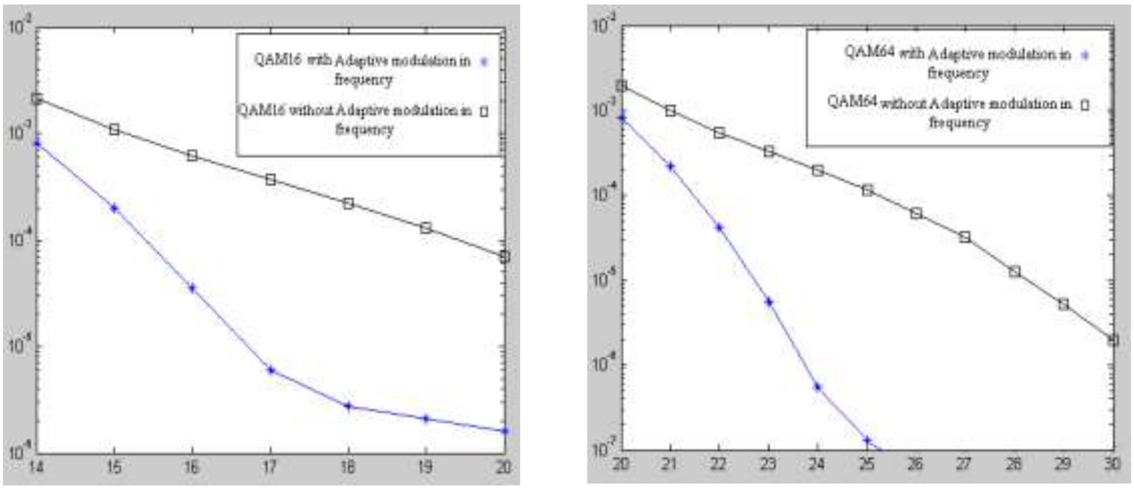
The simulation results for adaptive modulation system in MIMO with feedback are shown in Fig. 11 by using 2x2 MIMO, the results are made for three different speeds 5km/h, 40km/h and 100km/h. In Fig. 11(a) the adaptive modulation is compared to fixed QAM16 in range from 14dB to 20dB, and in Fig. 11(b) adaptive modulation is compared to QAM64 in range from 20dB to 30dB. The results shows that by using the adaptive modulation in MIMO channels we were able to fix the bit error rate under 10^{-4} which is the BER value required by LTE standards, while using fixed modulation in the same SNR range did not give us the required value of BER.



a) b)

Fig. 11. Adaptive modulation in MIMO channels with closed loop MIMO simulation results QAM16 (a) and QAM64 (b)

The results of simulation for the adaptive modulation in frequency domain by using OFDM model are shown in Fig. 12. In Fig. 12(a) the simulation is made for fixed QAM16 modulation over range from 14dB to 20dB and for an adaptive modulation system in frequency, where the system also uses QAM16 but with ability of adaptive modulation over 20 carriers. In Fig. 12(b) is the same but QAM64 is used instead with a range from 20dB to 30dB. The results in Fig. 12 showed that by using adaptive modulation in frequency the system is able to avoid fading in frequency domain, which will lower the bit error rate.



a) b)

Fig. 12. Adaptive modulation in frequency domain QAM16 (a) and QAM64 (b)

The simulation setup created for that analyzing SC-FDMA and OFDMA include 16-QAM baseband modulation. These modulations are being used in LTE and characterized by large sensitivity to nonlinear distortion. In the uplink of LTE standard, only low number of subcarriers is used for transmission. Therefore, in order to provide accurate simulation results, the following values of carriers have been chosen, N = {16; 64; 256}. Because BER performance of SC-FDMA does not depends on the number of subcarriers for transmission, therefore only the use of N = 64 subcarriers is shown.

With aim to get general observations, a set of input back-off (IBO) = {2, 4} parameters have been selected in simulation setup. No channel coding or any form of diversity is considered in order not to introduce other dependencies to the system performance. Fig. 13 shows the BER performance of SC-FDMA and OFDMA at 16-QAM operating with a Soft Limiter at IBO = 2dB. It can be observed from this figure, that SC-FDMA performs always better than OFDMA employing low {N = 16; 64} and moderate N = 256 number of subcarriers. This fact is in accordance with our expectations and the application of SC-FDMA according to this scenario is absolutely favorable.

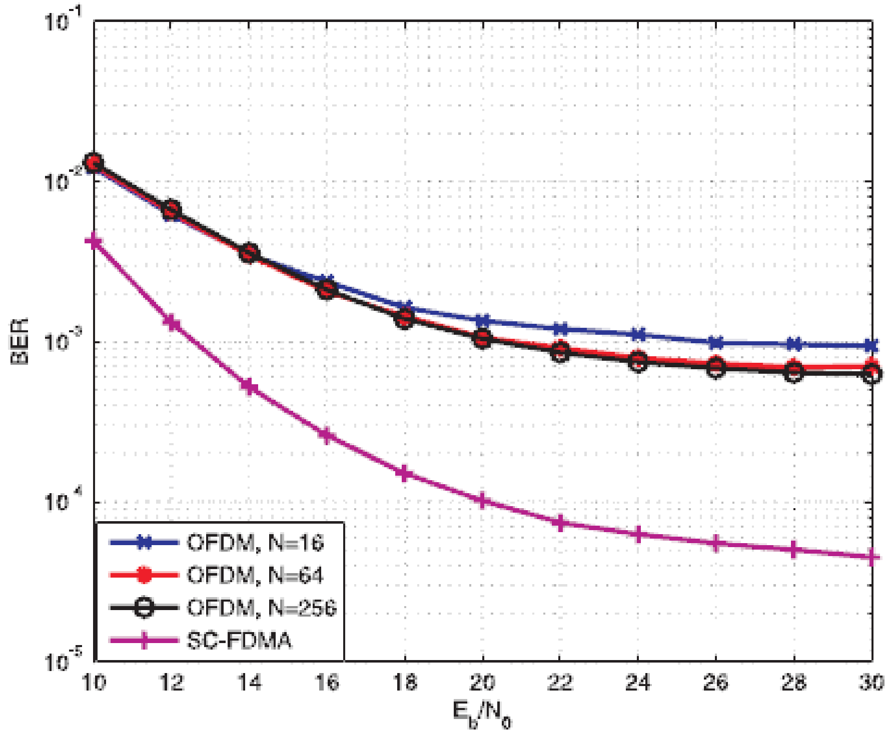


Fig. 13. BER performance of 16-QAM OFDMA and SC-FDMA systems operating with a soft-limiter at IBO = 2dB

However, with increasing parameter IBO, the situation has slightly changed. Simulation results depicted in Fig. 14 suggest that SC-FDMA performs always better than OFDMA employing low number of subcarriers {N = 16; 64}, on the other hand for high SNR, SC-FDMA provides similar results than OFDMA with N = 256.

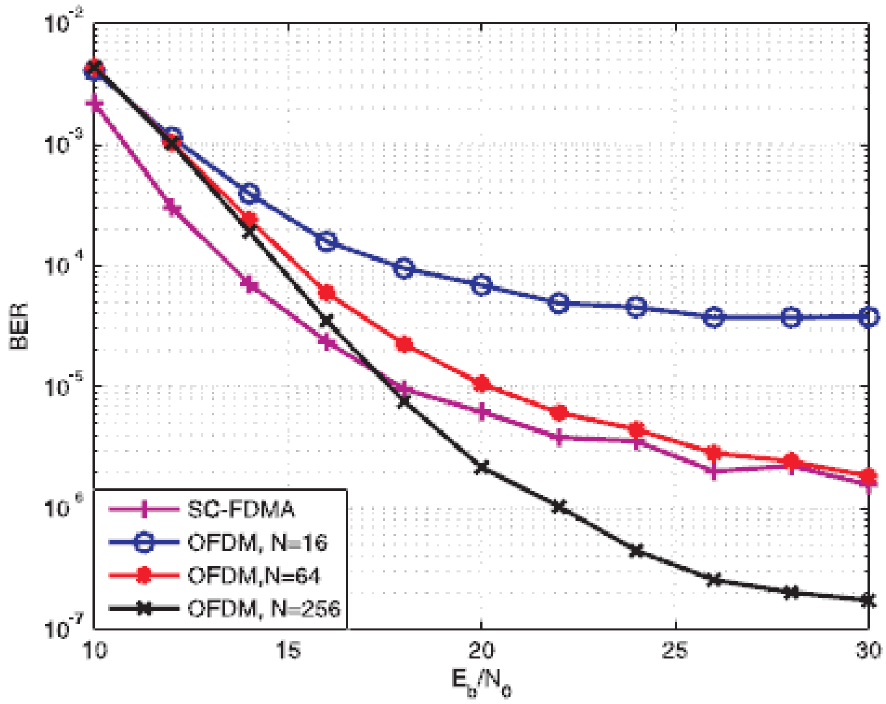


Fig. 14: BER performance of 16-QAM OFDMA and SC-FDMA systems operating with a soft-limiter at IBO = 4dB

Conclusion

1. The system uses the adaptation by changing the MIMO scheme between SFCB and selective transmitting, although the LTE technology with MIMO do not use the advantage of using the adaptive modulation in different MIMO channels and also through different frequencies which is considered a very important reserve that can improve the system performance.

2. The variety of schemes MIMO in LTE and the possibility of selecting a different schemes in adaptation to the conditions of the radio wave propagation, guarantees the achievement of high spectral efficiency up to 15 (bits / s) / Hz

3. The application of SC-FDMA is not always straightforward and there exist certain scenarios, typically for high SNR, where OFDMA can perform better than SC-FDMA. This is a special relevance of the upcoming next evolution of LTE, where OFDMA receives special interest even in the uplink of the cellular systems.

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