Performance of MIMO Assisted OFDM in 4G Networks

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ABSTRACT: *In recent years there has been a paradigm shift from voice centric to data centric wireless communication with data transmission greatly exceeding voice transmission in most developed markets. This phenomenon has caused anxiety in the operators worldwide to enhance the capacity of their wireless networks. Coupled with the demand for high data rate wireless transmission, the increased capacity requirement has prompted the operators and researchers to explore various options to achieve this end. The transition from 3G (Third generation) to 4G (Fourth generation) is defined by the need for increased data rate. Multiple -input multiple-output (MIMO) wireless technology in combination with orthogonal frequency division multiplexing (OFDM) is an attractive air-interface solution to meet the demands of 4G networks. MIMO provides a capacity advantage over multi-path channel while OFDM is particularly suited for high data rate wireless transmission which is also resistant to multipath fading. This paper provides an overview of the basics of MIMO-OFDM technology and focuses on performance in Fourth generation (4G) standard like Long Term Evolution (LTE). The challenges and potential research areas are proposed.*

Keywords: 4G, LTE, MIMO, OFDM, SC-FDMA

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1. Introduction

A wireless channel presents a multipath propagation environment which suffers through impairments like fading and intersymbol interference. Figure1 and Figure 2 depict a probability distribution function scenario with two and four multipath components respectively. Multipath propagation gives rise to Multipath fading Out of the many possible solutions OFDM comes out as a promising air interface which is resistant to multipath fading and provides good spectral efficiency. Multiple-Input Multiple-Output (MIMO) antennas and Multi-Carrier Code Division Multiple Access (MC-CDMA) are very promising candidates for simultaneous utilize in 4G systems, since they attain robustness, high spectral efficiency, and high data rates in rich scattering environments. Section II provides an overview of MIMO principles and fundamentals. It evaluates an efficient MIMO model based on Alamouti Scheme [1]. Section III provides an overview of OFDM along with the inherent challenges. Section IV highlights the choice of MIMO assisted OFDM air interface for 4G standards with a special emphasis over 3GPP LTE. Finally in the conclusion scope and future improvements are highlighted.

2A. MIMO Technology

MIMO systems have multiple antennas at the transmitter and the receiver. MIMO was initiated by the pioneering works of

Winters, Foschini and Gans [2-4]. Performance enhancement through MIMO in terms of increase in data rate and capacity has been established by [5]. Table 1 [6] succinctly summarizes the main applications of MIMO in wireless communication. The primary objective of MIMO emphasizes on the principle of diversity where the basic premise is that the signals fading independently may be combined coherently to enhance the throughput. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain [7]. By maximizing spatial diversity, power efficiency can be improved. Another MIMO technique uses a layered approach to increase capacity. One popular example of such a system is the vertical Bell Laboratories layered space time (VBLAST) architecture. Another technique utilizes the channel information at the transmitter. [8] specifies that channel matrix is decomposed using singular value decomposition (SVD) and these decomposed unitary matrices can be used as pre and post filters where Y and n are the receive and transmit vectors, respectively, and H is the complex channel matrix $Y(k) = X(k) + n(k)$;

H is the complex channel matrix and n is the noise vector, respectively. Each complex fading channel coefficient at the transmitter and receiver to achieve capacity gain.

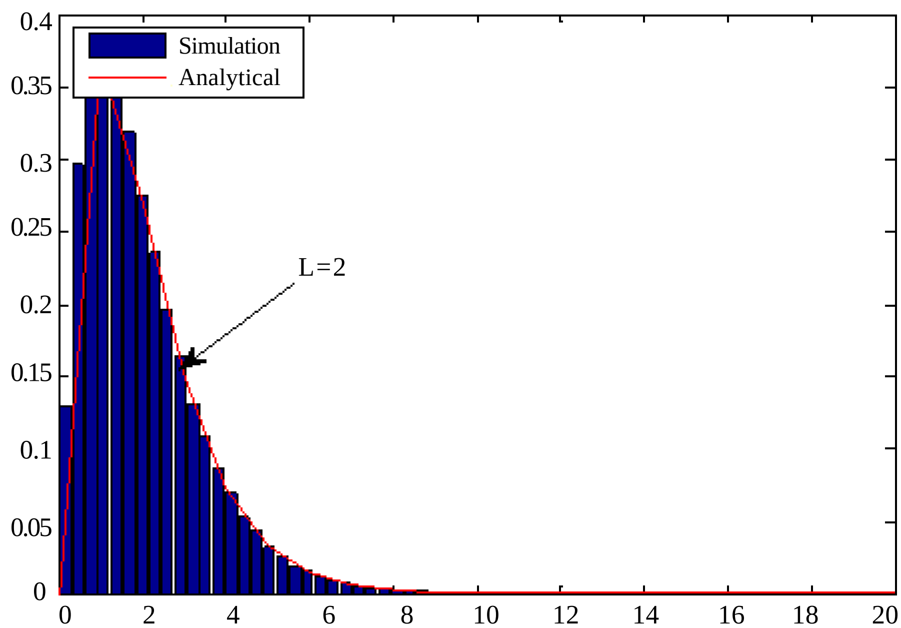

Figure 1. PDF of SNR with two multi path components

2B. MIMO System Model

MIMO system [9], a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of all N_t - N_r paths between the N_t transmit antennas at the transmitter and N_r receive antennas at the receiver. Then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information. A narrowband flat fading MIMO system is modelled as

$$H = \begin{bmatrix} h_{11} & h_{12} & \ldots\ldots\ldots h_{1t} \\ h_{21} & h_{22} & \ldots\ldots\ldots h_{2t} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ h_{r1} & h_{r2} & \ldots\ldots\ldots h_{r} \end{bmatrix}$$

where Y and n are the receive and transmit vectors, respectively, and H is the complex channel matrix $Y(k) = X(k) + n(k)$;

H is the complex channel matrix and n is the noise vector, respectively. Each complex fading channel coefficient h_{ij}, represents

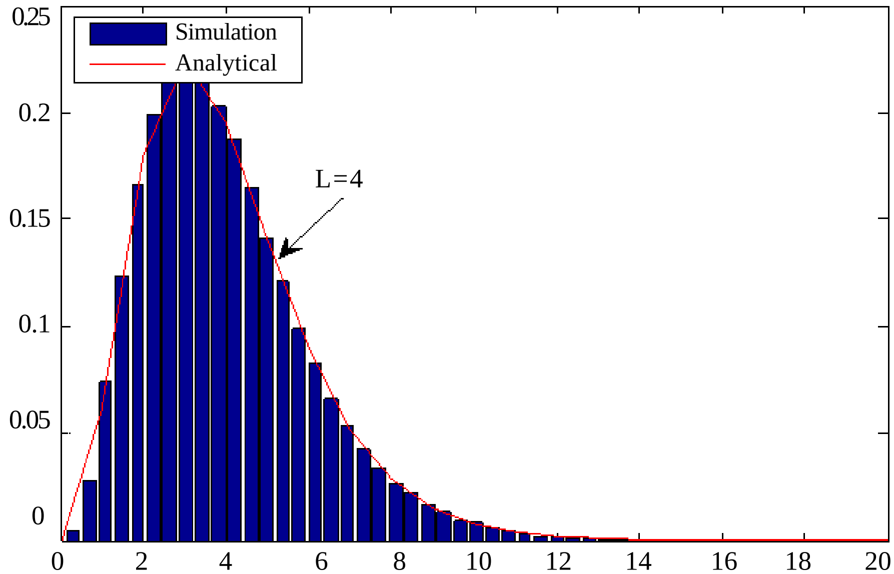

Figure 2. PDF of SNR with 4 multipath component

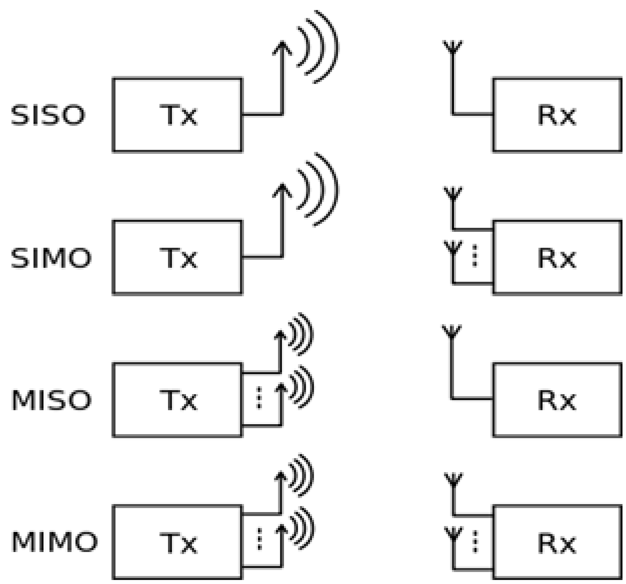

Figure 3. Various schemes in MIMO system

attenuation and phase shift between the i^{th} receive antenna and j^{th} transmit antenna. For fading MIMO channels, evaluation of capacity is given by Teletar (1999) [10],

$$C = E_H \log \det I_{NR} + \gamma / N_T HH^H$$

Figure 4 depicts the improvement in performance in the case when four transmit antennas are used against two. In both the cases rayleigh fading environment is considered. [11] Channels with multiple transmit and multiple receive antennas provide diversity along with additional degree of freedom. Alamouti coding scheme [1] is designed for two transmit antennas, however generalization to more than two antennas is possible. The performance of 2×2 MIMO scheme is summarized in Table 2 [10] The simple but elegant Alamouti coding scheme gives a better performance in terms of Diversity gain and degree of freedom.

Space Division Multiplexing(SDM)	SDM systems employ multiple antennas. They aim for increasing the throughput of a system in terms of number of bits per symbol transmitted
Space Division Multiple Access(SDMA)	SDMA exploits the unique spatial signature i.e. CIRs of individual users for differentiating amongst them
Spatial Diversity	In spatial diversity scheme such as space time block code or trellis code the multiple antennas are positioned as far apart as possible so that the transmitted signals of the different antennas experience independent fading resulting in maximum achievable diversity gain. Typical separation between antennas at base station and user end is 20 λ and $\lambda/2$
Beamforming	Typically $\lambda/2$ spaced antennas are used for the sake of creating a spatially selective transmitter/receiver beam. Smart antennas using beamforming have been employed for mitigating the effects of cochannel interfering signals and for providing beamforming gain

Table 1. Main applications of MIMO on wireless

Coding	Diversity gain	Degrees of freedom utilized per symbol time
Repetition	4	½
Alamouti	4	1
V- BLAST(ML)	2	2
V-BLAST (nulling)	1	2

Table 2. Comparison of different coding schemes for multiple transmit diversity

3. OFDM Technology

Technology is a leading indicator of standards. Hence the advent of OFDM technology along with it's effective implementation marked the evolution of 3G standards towards 4G. It is a key technology for 4G where multicarrier modulation (MCM) provides two distinct advantages [12]. First that an MCM signal can be processed in a receiver without the enhancement (by as much as 8 dB in some media) of noise or interference that is caused by linear equalization of a single-carrier signal, and second, that the long symbol time used in MCM produces a much greater immunity to impulse noise and fast fades. OFDM is a spectrum efficient kind of multicarrier transmission [13]. Figure 5 [14] shows a typical architecture of OFDM where the available bandwidth is subdivided into multiple frequency sub carriers As shown in Figure 5 in an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate (thus increased symbol duration) and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier.

The increased symbol duration improves the robustness of OFDM to delay spread. Furthermore the introduction of CP (Cyclic Prefix) can completely eliminate ISI (Inter-Symbol interference) as long as the CP duration is longer than the channel delay spread. The CP is typically a repetition of the last samples of data portion of the block that is appended to the beginning of the data payload. OFDM exploits the frequency diversity of means of OFDM symbols and in the frequency domain by means of sub-carriers.

The time and frequency resources can be organized into sub-channels for allocation to individual users. A very high degree of flexibility is required for 4G air interface [15]. To achieve this goal a combination of OFDM transmission technique and multiple

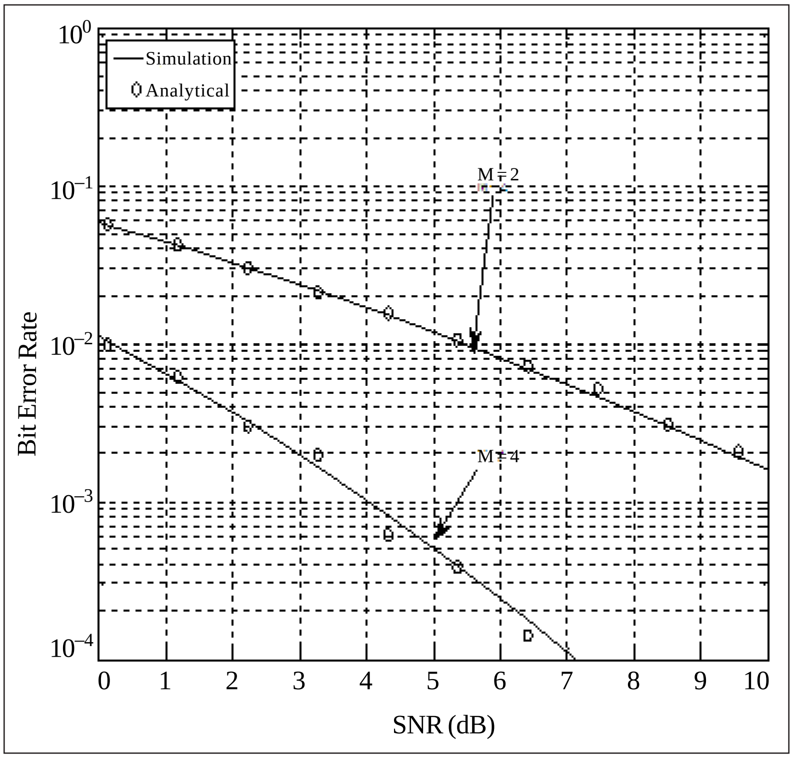

Figure 4. Performance for diversity order of 2 and 4

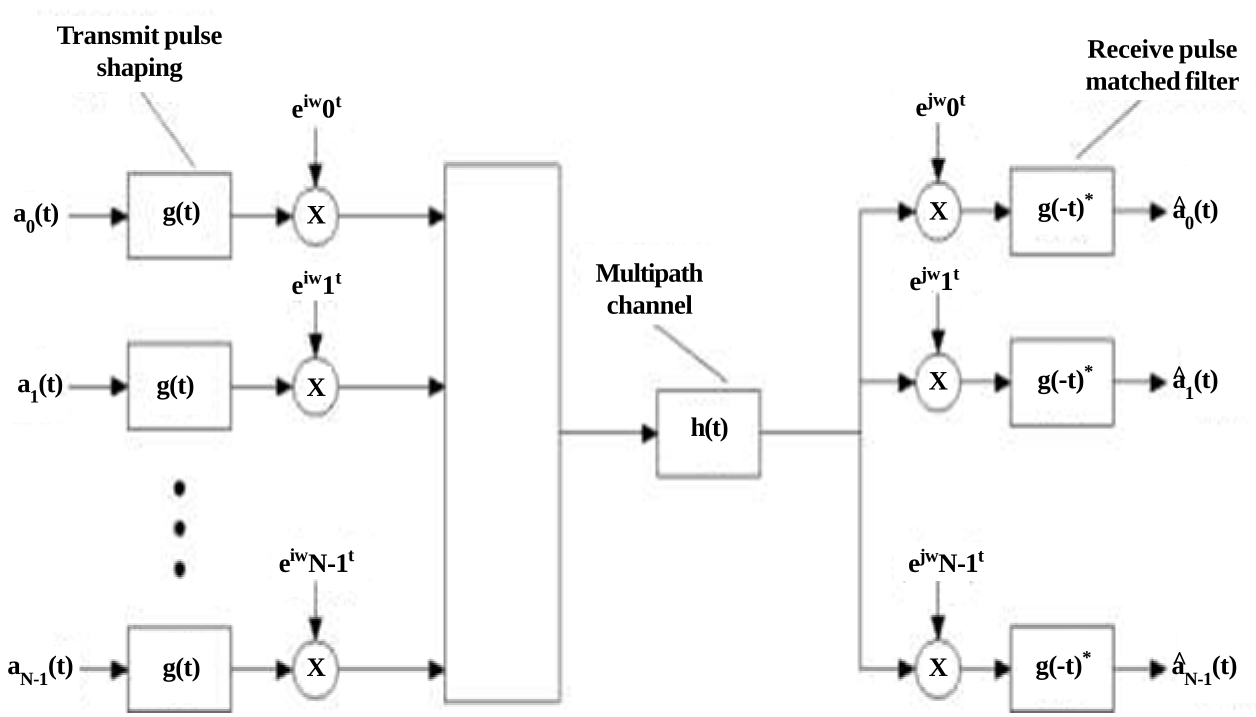

Figure 5. Basic Architecture of OFDM

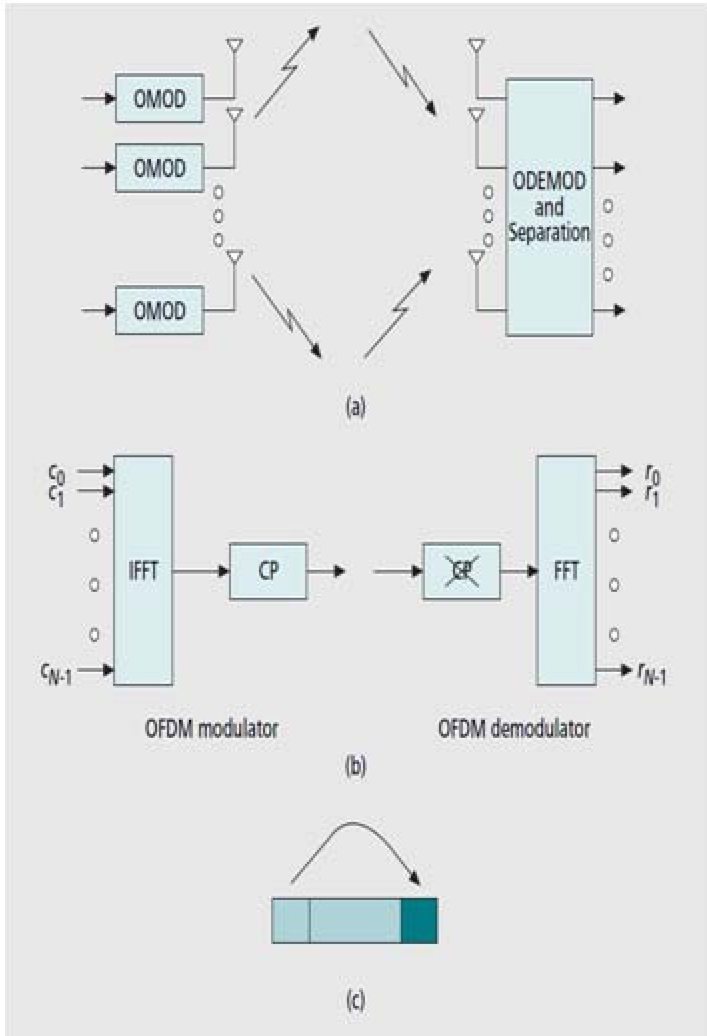

Figure 6. Schematic of MIMO OFDM

access scheme form an important factor. A comparison between different multiple access scheme for OFDM transmission leads to the fact that OFDM-FDMA, with an adaptation to the user-specific radio channels, leads to the best performance for the given parameters, if an optimal subcarrier allocation is assumed, followed by OFDM-CDMA and OFDM-TDMA [16].

4. MIMO-OFDM as an air interface

A. The choice of MIMO arrangement was motivated by the observation that the MIMO capacity increases linearly with the number of transmit antennas, provided that the number of receive antennas is equal to the transmit antennas [17]. OFDM incorporates the salient features of narrowband as well as wideband system. With the further proviso that the total transmit power is increased proportionately to the number of transmit antennas, a linear capacity increase is achieved upon increasing the transmit power. This is beneficial, since according to the classic Shannon-Hartley law the achievable channel capacity increases only logarithmically with the transmit power. Hence MIMO-OFDM may be considered a '*green*' transceiver solution. Figure 6 [18] illustrates a MIMO OFDM air interface where the multi antenna transmission is combined with OFDM technique. For high data rate transmission, the multipath characteristic of the environment causes the MIMO channel to be frequency selective. OFDM transforms such a channel into a set of parallel frequency flat MIMO channels. [19] The performance of MIMO assisted OFDM is governed by mobility which is analyzed in [20]. There is clear loss in spectral efficiency in high mobility scenarios. The performance of MIMO OFDM system is also governed by coherence of the wideband system [21].

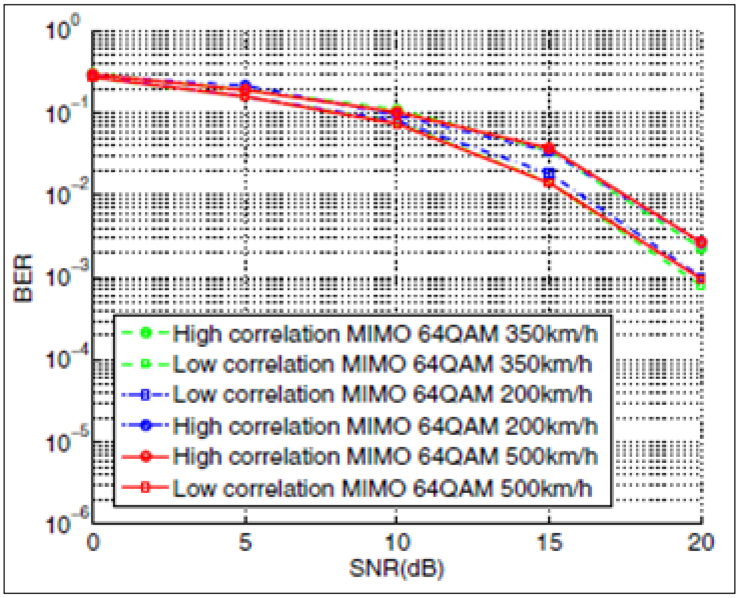

Figure 7. [22] BER performance of LTE system using 64 QAM. Comparison between high and low correlation MIMO channels for different speeds

B. Long Term evolution(LTE) "*With 145 LTE networks commercially launched and over 560 user devices announced in the market supporting millions of customers worldwide, LTE technology is mainstream and firmly established as the fastest developing mobile system technology ever*," said Alan Hadden, President of the GSA..GSA forecasts that 234 LTE networks will be commercially launched in 83 countries by the end of 2013. LTE is a 4G technology developed by 3GPP. LTE uses OFDM as the downlink and SC-FDMA (single carrier FDMA in the uplink to mitigate peak to average power ratio. Figure 7 [22] shows the performance of MIMO OFDM for BER vs SNR. Due to the high mobility channel equalization is implemented to mitigate the Doppler effect. However wherever there is high correlation between MIMO channels BER is much higher.

5. Conclusion

In this paper the principles of MIMO and OFDM are outlined. The performance improvement is demonstrated for MIMO. The combination of MIMO with OFDM yields a suitable interface for 4G(LTE) standard. The challenges and limitations can be dealt with to give a throughput in excess of 100 Mbps.

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