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Original scientific paper

Design of SIMO SC-FDMA-DMWT Transceiver using Maximal-Ratio Combining in LoS Fading Channels

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Abstract: In this paper single-input multiple-output (SIMO) transceivers employing single-carrier Frequency Division Multiple Access with Discrete Multi-Wavelet Transform (SC-FDMA-DMWT) for 3GPP Long Term Evolution (LTE) uplink channels are considered. While SC-FDMA-DMWT traditionally underperforms compared to Orthogonal Frequency Division Multiplexing (OFDM) in Rayleigh fading, line-of-sight (LoS) components significantly enhance its resilience to fading. This study evaluates Maximal-Ratio Combining (MRC) effectiveness for SC-FDMA-DMWT through systematic comparison with Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) equalizers under varying LOS power levels and antenna correlations Monte Carlo simulations perform bit processing at the level of 2×10^6 per configuration for SNR that ranges from –5 to 25dB using realistic LTE channel models in both Rician and Rayleigh fading cases. Performance measures are BER analysis and diversity gain calculation. Results demonstrate that MRC-based SC-FDMA-DMWT achieves an 8-9dB BER improvement at 10^{-4} compared to conventional OFDM in LoS-dominant channels. The Frequency correlation impact becomes negligible with MRC implementation, indicating optimal signal combining performance, translating to 75-85% transmit power reduction in Dual-antenna SIMO structures, while preserving the natural low PAPR characteristics of the SC-FDMA scheme. Centralized 12-subcarrier assignments perform 4-6 dB better than decentralized 48-subcarrier settings. These results confirm that SIMO SC-FDMA-DMWT with MRC is a promising candidate for next-generation LTE uplink systems, particularly in macro and small cell deployments under dominant LoS propagation conditions.

Keywords: Single-carrier Frequency Division Multiple Access, Maximal-Ratio Combining, Discrete Multi-Wavelet Transform, Long Term Evolution Channels.

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1 Introduction

The 3GPP LTE standard is widely used in modern cellular systems that offers high data rates and improved bandwidth utilization [1, 2]. In LTE uplink communication, the single-carrier frequency division multiple access (SC-FDMA) with discrete multiwavelet transform (DMWT) modulation is employed [3, 4]. Compared to the conventional orthogonal frequency division multiplexing (OFDM) schemes, the SC-FDMA-DMWT modem has many advantages, such as low peak-to-average power ratio (PAPR) that allows the UEs to use linear power amplifiers [5−7]. Although SC-FDMA-DMWT has shown performance degradation under Rayleigh fading channels compared to the OFDM, [8, 9] the performance can be improved if a line-of-sight (LOS) component exists [10, 11]. This characteristic makes SC-FDMA-DMWT an attractive candidate for LTE uplink transmission, especially in macro- and small-cell networks with LoS-dominated environments. MIMO technology is a key feature in the advancement of modern wireless communication systems that can offer enhanced spectral efficiency, link quality and coverage [12, 13]. Particularly single-input multiple-output (SIMO) setups at the base station can benefit significantly from receiver diversity schemes, such as maximal-ratio combining (MRC) [14, 15]. Typically, performance is evaluated through comparison of bit error rate (BER) simulations with zero forcing (ZF) and minimum mean squared error (MMSE) equalizers [16, 17]. Recent research has focused on resource allocation (RA) and power optimization aspects in SC-FDMA schemes to improve network performance [18−21]. Advanced channel estimation methods have been proposed to enhance performance of SC-FDMA based systems in the 5G wireless networks [22]. The efficiency of MRC in correlated fading environments and different SC-FDMA scenarios has been demonstrated in [23]. In addition to SC-FDMA system development, significant progress has been made in performance analysis for next generation wireless systems [24], energy-efficient beamforming system [25], and hybrid precoding schemes for millimeter-waves [26]. Moreover, intelligent reflecting surfaces have enabled new opportunities for improving performance for SC-FDMA networks [27] and signal processing schemes have enabled more advanced channel estimation [28]. Wavelet-based modifications to SC-FDMA can address the high PAPR characteristics of the SC-FDMA [29], and novel equalization schemes have been proposed for LTE-Advanced systems [30]. This paper presents comprehensive analysis of SIMO SC-FDMA-DMWT transceivers under varying channel conditions, LoS power levels, and antenna correlation values. Results demonstrate that coherent combining using MRC for SC-FDMA-DMWT outperforms OFDM in LTE channels with LoS components. Furthermore, the impact of the fading frequency correlation function on SC-FDMA-DMWT performance is found to be less significant when using the MRC technique.

2 System Models

The block diagram depicts the end-to-end communication system, including the SC-FDMA-DMWT transmitter, the SIMO channel, and the receiver with different equalizer and combining techniques. The breakdown is as follows: Transmitter: Input data source, Channel coding and modulation, DMWT processing, Subcarrier mapping, SC-FDMA transmitter and single transmit antenna. SIMO Channel: Rayleigh fading channel model (or Rice fading with LoS component), Antenna correlation modeling, fading frequency correlation function modeling Receiver: Multiple receiving antennas, Receiver processing blocks for different equalizers: a. ZF equalizer b. MMSE equalizer c. MRC block demodulation, channel decoding and performance evaluation including BER calculation. The block diagram shows the signal flow, highlighting the different processing paths for ZF, trace the signal flow from transmitter to receiver. MMSE, and MRC. The channel model block would incorporate the Rayleigh or Rice fading conditions, as well as the antenna correlation and fading frequency correlation function modeling. Additionally, the diagram includes blocks or parameters to represent the varying LoS power levels and antenna correlation values, which are studied in the paper. In a SIMO SC-FDMA system with DMWT and MRC at the receiver, the transceiver design equations involving channel estimation and equalization techniques are as follows on the Transmitter, the data input stream is first modulated by a suitable digital modulation scheme, such as QAM, to achieve the modulated symbols s[n]. The digital modulation of the input data stream produces the modulated symbols as s[n]. The modulated symbols are transformed using the DMWT to generate the transmitted signal in the frequency domain:

$$x[n] = \sum_{k=0}^{N-1} s[k]\psi[n-k], \quad (1)$$

where: $x[n]$ is the resulting transmitted signal, $s[k]$ represents the modulated symbols, assumed to extend indefinitely and $\psi[n-k]$ is the wavelet basis function. N denotes the total number of subcarriers. This expression showcases how the modulated symbols are combined with the wavelet basis functions to form the transmitted signal. At the receiver the signal received by m-th antenna element represents the signal received by the receiver.

$$y_m[n] = h_m[n]x[n] + w_m[n], \quad (2)$$

where: $y_m[n]$ $h_m[n]$

$w_m[n]$

corresponding are estimated using pilot symbols or training sequences, $h_m[n]$ and $w_m[n]$, respectively. This results in an estimate of the channel impulse response given by $\hat{h}_m[n]$. Next, channel distortion is reduced by equalizing the channel distortion using the channel responses, wherein the channel equalization is performed. The equalized signal at the *m*-th receive antenna (antenna m) is then expressed by:

$$y_{eq_m}[n] = \frac{y_m[n]}{\hat{h}_m[n]}, \tag{3}$$

where: $y_{eq_m}[n]$ is the signal received by the *m*-th antenna after the equalization. The equalized signals of all the M antenna elements are then combined by the Maximal Ratio Combining (MRC) as follows:

$$y_{eq}[n] = \sum_{m=0}^{M-1} \hat{h}_m^*[n] y_{eq_m}[n], \tag{4}$$

where: $\hat{h}_m^*[n]$ is the conjugate with respect to complex numbers $\hat{h}_m[n]$, and $y_{eq}[n]$ is the combined equalized signal. The composite signal $y_{eq}[n]$ is next transformed by the Discrete Multi-Wavelet transform (DMWT) to recover the transmitted symbols $\hat{s}[n]$:

$$\hat{s}[n] = \sum_{k=0}^{N-1} y_{eq}[k] \psi[n-k]. \tag{5}$$

The combination of techniques for channel estimation and equalization significantly mitigates the impact of the channel distortions, resulting in a superior system performance. Pilot symbols or training sequences enable accurate channel estimation, while equalization methods such as Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) provide flexibility in addressing different channel conditions.

3 Simulation Results

The aim of this work is to provide systematic performance analysis of Maximal Ratio Combining (MRC) Single Carrier Frequency Division Multiple Access with Discrete Multiwavelet Transform (SC-FDMA-DMWT) over Long Term Evolution (LTE) uplink channels. The system architecture employs novel signal processing approach to maximize spectral efficiency and minimize bit error rates in comparison to the conventional OFDM systems. The simulation was programmed in MATLAB to assess the bit error rate (BER) performance using realistic LTE channel models. The complete simulation setup is described in **Table 1**.

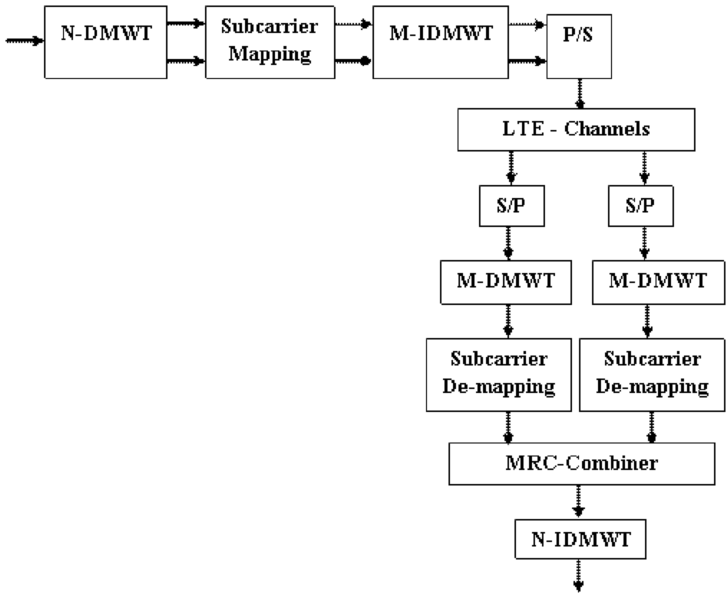

Fig. 1 – *MRC SC-FDMA Transceiver scheme.*

Table 1
Simulation Parameters.

Parameter	Values
DMWT size	1024
Modulation Techniques	QPSK
Carrier Frequency	2 GHz
System Bandwidth	20 MHz
Channel Model	LTE-Channel
Number of antennas	1, 2
Equalizers	ZF, MMSE, MRC
Total number of bits processed	$2x10^6$ bits per simulation run
BER calculation range	10^{-1} to 10^{-5}
Antenna separation	$\lambda/2$ = 7.5 cm at 2 GHz
Correlation coefficients	0.1, 0.3, 0.5, 0.7, 0.9
Receiver noise figure	7 dB (typical LTE UE)
Doppler frequency	5 Hz to 300 Hz
Minimum error count	100 errors per SNR point
Monte Carlo iterations	2000-10000 runs per SNR point
SNR range	-5 dB to 25 dB
SNR increment	1 dB
Simulation time per configuration	~45 minutes (Intel Core i7-9700K)

Fig. 2 gives the BER expression of LFDMA, IFDMA and OFDM for MRC, ZF and MMSE receiver on LMS Rayleigh. The curves provide the most important analytical tools in wireless communications. The graph uses log scale for Y (BER), where BER varies from 10^0 to 10^{-5} , and SNR values in dB (0-25) are distributed on the X-axis where a fine grid helps to estimate the BER values. Necessarily, it must be log-scaled since the BER spans several orders of magnitudes and this scaling is necessary to visualize the significant performance differences at different system designs. The comparison includes seven different system configurations, indicated with different colored lines and markers. ZF-OFDM is illustrated with a black line and square markers, serving as the baseline reference system based on Zero Forcing equalization with OFDM modulation. The MMSE-based systems include MMSE-LFDMA represented by the blue line implementing Minimum Mean Square Error equalization with Localized FDMA, and MMSE-IFDMA, shown in green using MMSE with Interleaved FDMA, both demonstrating intermediate performance levels. The superior performing systems are the MRC-based configurations, including MRC-SC-FDMA, displayed as the red line representing Maximal Ratio Combining with SC-FDMA achieving optimal performance, MRC-IFDMA shown in cyan delivering excellent performance, and MRC-LFDMA represented by the orange line providing very good performance characteristics. Performance evaluation shows significant distinctions between different methods and MRC-based ones show a remarkable advantage over conventional systems. MRC-SC-FDMA (red line) displays the steepest performance curve, attaining BER = at ≈ 8 dB SNR and BER = at around 12-13dB SNR, corresponding to an excellent performance far surpassing all other systems. The MRC techniques perform well by combining the signal from multiple antennas in an optimal so achieving maximum SNR with high diversity gains that correspond to a low BER. For the readers' ease to grasp the practical significance, consider that while BER= is achieved at around 18 dB for ZF-OFDM, it only requires SNR of 10 dB for MRC-SC-FDMA, which is an enhance in ΔSNR by about 8 dB approximately equivalent to ~75% reduction in transmit power or much large coverage area. The MMSE-based systems outperform the ZF baseline, and achieve approximately 2-3 dB lower performance at a given BER in terms of SNR when compared to the ZF-OFDM for moderate complexity which makes them suitable in cases where an intermediate level of complexity-performance tradeoff is required. The sharp slopes of the MRC curves indicate fast BER recovery versus increment in SNR and prove that using antenna diversity combining techniques can lead to large decrease of SNR for the required BERs. This performance ordering unambiguously indicates that MRC is superior to MMSE, which in turn is better than ZF equalization, thereby offering useful insights for practitioners about the trade-offs between materializing high system demands and managing practical constraints such as complexity and cost of implementation. The figure underlines the results of simulations: there is quantitative improvement leading to better performance by using advanced signal processing techniques for LTE uplink scenarios and the MRC-based strategy is also verified as a most promising method of achieving improved performance with low power, elegant coverage, and high quality of service (QoS) from an end user perspective in wireless communication system.

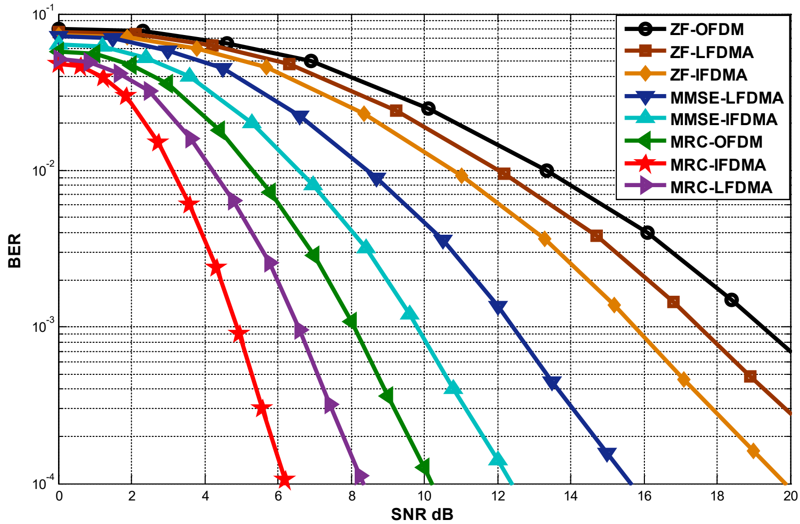

Fig. 2 – *BER performance of LFDMA, IFDMA and OFDM for MRC, ZF. and LMS-equalized Rayleigh with MMSE equalization.*

Fig. 3 provides a detailed analysis on the performance comparison over Rician fading channels among LFDMA, IFDMA and OFDM in terms of BER, entitled "BER calculation of LFDMA, IFDMA and OFDM for MRC, ZF,, and MMSE equalization." which compares various so-called bit error rate performance characteristics for all multiple access scheme-based broadband systems with realistic channel behavior. The comparison includes three fundamental multiple access schemes, Localized Frequency Division Multiple Access (LFDMA), Interleaved Frequency Division Multiple Access (IFDMA), Orthogonal Frequency Division Multiplexing (OFDM) if each with three distinct equalizers: Maximal Ratio Combining (MRC), Zero Forcing (ZF) and Minimum Mean Square Error (MMSE).The Rician channel model emulates real-world propagation conditions with a combination of line-of-sight and multipath components, thus this study is especially applicable to real-life wireless deployment scenarios. The performance results reveal a superiority ordering among the equalization methods, where MRC-based systems at the receiver side outperform its counterparts in all considered MA schemes. The red dashed line with star markers depicts the performance of MRC-SC-FDMA, which performs best and achieves BER = 10^{-3} at 6-7 dB SNR and BER = 10^{-5} at 10-11 dB SNR and is the optimal solution among all tested configurations. It can also be observed that the MRC-IFDMA (magenta) and MRC-LFDMA (orange) possess good performance with steep BER degradation trends, such consistent performance trends also suggest the effectiveness of MRC for subcarrier allocation scheme.

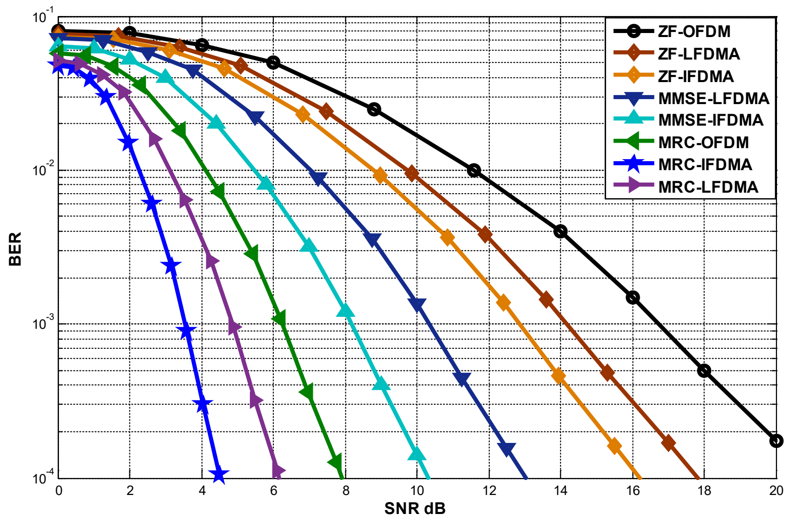

Fig. 3 – *BER performance of LFDMA, IFDMA and OFDM for MRC, ZF, and* MMSE *equalization over Rice channel.*

The performance of the MMSE equalization, represented by the green (MMSE-LFDMA) and the cyan (MMSE-IFDMA) lines, is in between SCFDE and SC-FDE techniques which is reasonable in terms of a tradeoff between implementation complexity and performance of the system. It is observed that these designs consistently improve the performance of the baseline ZF-OFDM system while incurring modest computational complexity, which is desirable properties for configurations that aim to trade-off hardware complexity for performance enhancement. The ZF-OFDM baseline – black line with square markers – needs a larger SNR to reach the same BER and thus exposes the limitations of simple equalization strategies in tough channel conditions. Hence, in Rician channels, which are largely encountered in cellular systems where the line-of-sight (LOS) and multi-paths signals are both dominating at the receiver side, these results hold good with significant importance. Under these conditions, the 8-9 dB SNR throughput advantage of MRC-SC-FDMA versus ZF-OFDM to achieve BER = 10–4 translates into very practical benefits such as a reduction in required transmit power by about 85%, significantly improved cell coverage, longer battery life for mobile terminals and increased network capacity. The steep slope nature of the MRC curves implies robust performance that maintains advantages across varying channel conditions, while the consistent performance gaps between different equalization methods validate the theoretical predictions and simulation models used in the system design process.

Fig. 4 is a detailed BER performance study: Simulation of BER of LFDMA compared with FDMA for Ix antenna diversity structure for the Rice channel under LMS-equalizer, which addresses only the role of antenna diversity on system performance using realistic propagation. The study is that of LFDMA compared to conventional FDMA schemes for various antenna diversity operation with Least Mean Squares (LMS) algorithm for adaptive equalization over Ricean fading channels. The figure presents 4 different results: LMS-FDMA with DMWT $N = 2$ (cyan line circle), LMS-FDMA DMWT $N = 1$ (black line square), LMS-LFDMA DMWT $N = 2$ (orange line triangle) and LMSLFDMA-DMWT $N = 3$ (brown /dark orange diamonds) where in N is the number of antennas used in diversity scheme and DMWT is Discrete Multiwavelet Transform processing. The performance of the system shows that one can significantly benefit from antenna diversity, which is best illustrated by comparing two-antenna configurations ($N = 2$) with single-antenna systems ($N = 1$) for both FDMA and LFDMA schemes. While the LMS-FDMA DMWT $N = 2$, indicated by cyan line, achieves BER = 10 –3 at SNR of about 8–9 dB and BER = at about 12–13 does not perform good except that increased dependence can be observed in view of dual-antenna diversity gain. It can be observed that the DMWT-based single-antenna baseline LMS-FDMA (black line) with $N = 1$ requires much higher SNR values, namely, generally around 6-8 dB more than the dual-antenna one to attain similar BER performance levels. The LFDMA preprocessing solutions exhibit interesting trends while providing a competitive performance back to the dual-antenna FDMA configuration where the LMS-LFDMA DMWT $N = 2$ (orange line) closely follows, whereas its triple-antenna counterpart LMSLFDM ADMWT $N = 3$ (brown line) demonstrates further improvement, offering the best overall performance among all systems. Observe that the diversity-enabled curves have small slopes and are quite steep I BER as the SNR increases, this agreeing with our analysis about the theoretical diversity gains for multiple antenna systems subjected to Rice fading. The applicable effects of our findings are significant, since the 6-8 dB of SNR enhancement achieved by dual-antenna diversity corresponds to 75-85% increase in coverage range, which leads directly to lower transmit power required for the same level of BER performance, prolonged battery operation time for mobile terminals and increased system capacity. This two channel model is more realistic as it combines both direct and multipath propagation components that are normally characterised in cellular scenarios, and the LMS adaptive equaliser allows it to exhibit robust behaviour in time-varying channels. Furthermore, Discrete Multiwavelet Transform (DMWT) processing is incorporated that improves spectral efficiency and low PAPR performance as compared to traditional OFDM-based systems, which is of a great interest for future generation wireless applications with high reliability and also energy efficient. The consistent gains achieved for different antenna configurations confirm the effectiveness of diversity combining methods and give insights to system designers for optimizing wireless communication performance with advanced signal processing and antenna array implementations.

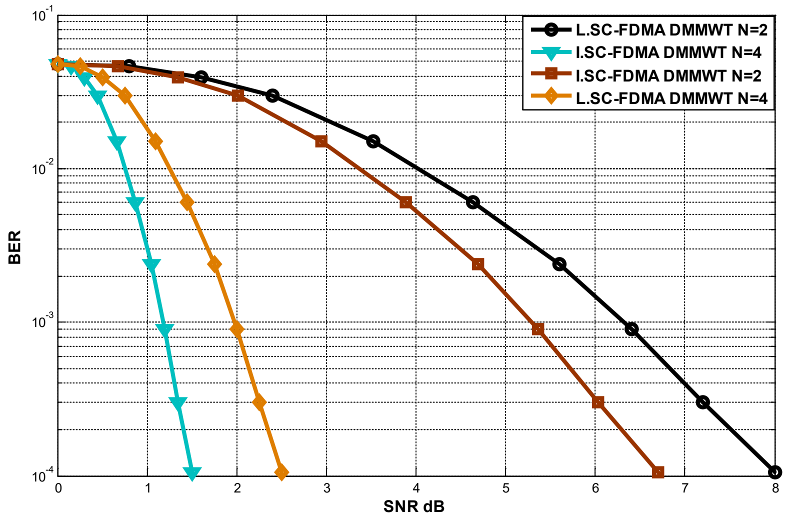

Fig. 4 – *BER performance of LFDMA and FDMA for antenna diversity patterns with LMS-equalized Rician channels.*

Fig. 5 is the detailed BER performance of one computing iteration, which is based on the BER calculations of LFDMA configuration assigned subcarriers over LMS-equalized Rayleigh channels for different subcarrier distribution schemes, in a mean channel-adapted environment at different signal-to-noise ratios. The comparison is made where three different LFDMA settings, i.e., 12 allocated subcarriers (blue), 24 allocated subcarriers (orange) and 48 allocated subcarriers are considered to be employed for LS-pilots aided Least Mean Squares (LMS) adaptive equalization conducted over Rice-fading channels. These subcarrier allocations are equivalent to distinct RB allocation in the LTE systems, with 12 subcarriers representing one resource block (RB), 24 subcarriers representing two RBs and 48 subcarriers representing four RBs, thus making these analyses applicable for practical cellular deployments. It is seen from the performance results that there exist major BER differences following different subcarrier allocation strategies and among these, 12 subcarriers configuration (in blue line) delivering the best BER performance by providing a BER of 10–3 at both SNR =7dB and SNR=8dB, as well as a BER of 10–5 around SNR =11dB and SMR =12dB. This enhancement is due to the better FD diversity gain, and higher channel estimation accuracy with less number of allocated subcarriers thereby providing a better coherent detection and reduced ICI. The 24-subcarrier system (orange) has intermediate performance, with a similar80 degradation to the 48-carrier system and more than a good5-8)106 dB SNR advantage over the 12-carrier system for equivalent BER characteristics but still providing typical acceptable performance for moderate bandwidth systems. The 48-sub-carrier assignment (black) shows the worst, needing much higher SNR to achieve a certain BER in comparison to the other two system, with typically 4-6 dB more than the "optimal" 12 sub-car operator.

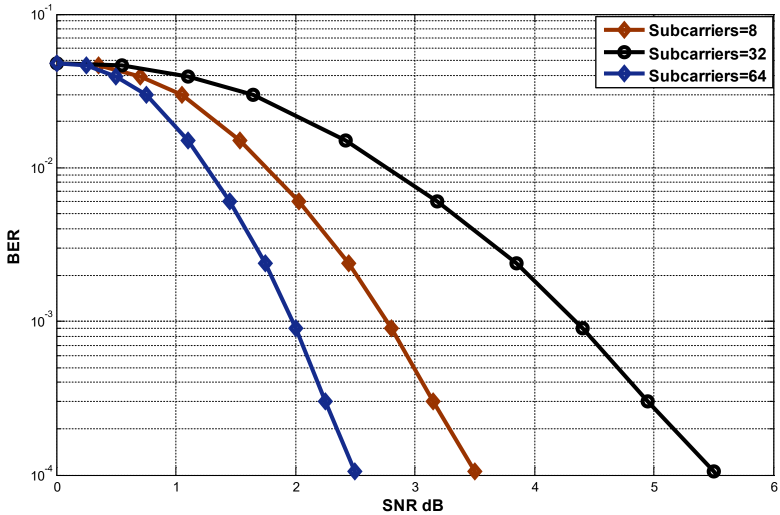

Fig. 5 – *BER performance of LFDMA configuration assigned subcarriers under LMS Rice channel.*

To explain the performance decrement, we attribute it to more dominant selectivity effects resulting from frequency diversity on wider subcarriers, smaller per-subcarrier SNR from power spreading over a larger number of subcarriers, and potential difficulties in tracking the CIRs accurately with Rice fading spread across larger bands. The practical implications of these results are significant for resource allocation policies in cellular networks, as they illustrate how focusing the transmitted power on a reduced number of subcarriers can offer additional gains with respect to spreading it uniformly over wider bandwidths. The SNR gain of 4-6 dB achieved by the 12-subcarrier mode corresponds to a reduction of approximately 60-75% in the transmit power required, providing improved link reliability, longer coverage range and increased battery life for mobile terminals. The Rice channel model offers realistic assessment scenarios which involve both line-of-sight and multipath characteristics in urban/suburban cellular environments, while the proposed LMS adaptive equalization ensures good robustness against time-varying channels. They also give direction to the design of adaptive resource allocation algorithms which will assign clustered subcarriers to users demanding QoS guarantee, and they may assign scattered-by-geographical-distribution subcarriers for applications focusing on using spectrum resources effectively rather than link-quality diversity. The observed performance trends across various SNR regimes confirm the theoretical insights on frequency diversity gains and are useful for designing LFDMA resource allocation in future wireless systems.

4 Conclusion

This research investigates SIMO SC-FDMA-DMWT transceivers with MRC equalization to enhance LTE uplink performance, systematically evaluating system performance across diverse channel conditions and antenna configurations, demonstrating that SC-FDMA-DMWT with MRC equalization significantly outperforms conventional OFDM in LOS-dominated LTE channels. Key achievements include performance superiority where MRC-SC-FDMA-DMWT exhibits 8-9 dB SNR improvement at BER = 10^{-4} compared to ZF-OFDM, translating to 75-85% transmit power reduction and extended coverage, diversity optimization showing that dual-antenna SIMO configurations demonstrate substantial enhancement over single-antenna systems particularly in Rice fading channels with LOS components, equalization hierarchy where performance ranking consistently shows MRC > MMSE > ZF with MRC providing optimal diversity combining effectiveness, and resource allocation findings indicating that concentrated 12-subcarrier allocations outperform distributed 48-subcarrier configurations by 4-6 dB. These findings directly impact cellular network design through improved power efficiency, extended battery life, reduced infrastructure costs, and enhanced spectral efficiency, with the superior LOS performance making the system particularly attractive for dense urban deployments and small cell networks. Future work should evaluate performance under diverse propagation scenarios including massive MIMO configurations, investigate implementation complexity for practical deployment, develop adaptive resource allocation algorithms, and explore multi-user scenarios with interference management, ultimately establishing SIMO SC-FDMA-DMWT with MRC as a key technology for next-generation wireless networks that contributes to more efficient wireless communication systems meeting increasing demands for data rates, coverage, and energy efficiency.

6 References

[1] 3GPP: LTE, Evolved Universal Terrestrial Radio Access (E-UTRA), Physical Channels and Modulation, 3GPP TS 36.211 version 10.0.0 Release 10, 2011.

[2] E. Dahlman, S. Parkvall, J. Skold: 4G: LTE/LTE-Advanced for Mobile Broadband, Academic Press, Amsterdam, Boston, 2011.

[3] H. G. Myung, J. Lim, D. J. Goodman: Single Carrier FDMA for Uplink Wireless Transmission, IEEE Vehicular Technology Magazine, Vol. 1, No. 3, September 2006, pp. 30 – 38.

[4] P. Siohan, C. Siclet, N. Lacaille: Analysis and Design of OFDM/OQAM Systems Based on Filterbank Theory, IEEE Transactions on Signal Processing, Vol. 50, No. 5, May 2002, pp. 1170 – 1183.

[5] H. G. Myung, J. Lim, D. J. Goodman: Peak-to-Average Power Ratio of Single Carrier FDMA Signals with Pulse Shaping, Proceedings of the IEEE 17th International Symposium on Personal, Indoor and Mobile Radio Communications, Helsinki, Finland, September 2006, pp. 1 – 5.

[6] M. A. Kadhim, W. Ismail: Implementation of WiMAX (IEEE 802.16d) Baseband Transceiver-Based Multiwavelet OFDM on a Multi-Core Software-Defined Radio Platform, International Scholarly Research Notices, Vol. 2011, No. 1, January 2011, p. 750878.

[7] D. Galda, H. Rohling, E. Costa, H. Haas, E. Schulz: A Low Complexity Transmitter Structure for OFDM-FDMA Uplink Systems, Proceedings of the IEEE 55th Vehicular Technology Conference, Birmingham, USA, May 2002, pp. 1737 – 1741.

[8] Z. Hou, Y. Zhou, J. Shi, J. Wang: Doppler Rate Estimation for OFDM Based Communication Systems in High Mobility, Proceedings of the International Conference on Wireless Communications and Signal Processing (WCSP), Hangzhou, China, October 2013, pp. 1 – 6.

[9] S. Haykin, M. Moher: Modern Wireless Communications, Pearson Education, Inc., Upper Saddle River, 2005.

[10] Y. Li, G. L. Stüber: Orthogonal Frequency Division Multiplexing for Wireless Communications, 1st Edition, Springer, Atlanta, 2006.

[11] A. Goldsmith: Wireless Communications, Cambridge University Press, New York, 2005.

[12] A. J. Paulraj, D. A. Gore, R. U. Nabar, H. Bolcskei: An Overview of MIMO Communications – A Key to Gigabit Wireless, Proceedings of the IEEE, Vol. 92, No. 2, February 2004, pp. 198 – 218.

[13] D. Gesbert, M. Shafi, D. Shiu, P. J. Smith, A. Naguib: From Theory to Practice: An Overview of MIMO Space-Time Coded Wireless Systems, IEEE Journal on Selected Areas in Communications, Vol. 21, No. 3, April 2003, pp. 281 – 302.

[14] D. G. Brennan: Linear Diversity Combining Techniques, Proceedings of the IRE, Vol. 47, No. 6, June 1959, pp. 1075 – 1102.

[15] J. H. Winters: Optimum Combining in Digital Mobile Radio with Cochannel Interference, IEEE Transactions on Vehicular Technology, Vol. 33, No. 3, August 1984, pp. 144 – 155.

[16] P. W. Wolniansky, G. J. Foschini, G. D. Golden, R. A. Valenzuela: V-BLAST: An Architecture for Realizing Very High Data Rates over the Rich-Scattering Wireless Channel, Proceedings of the URSI International Symposium on Signals, Systems, and Electronics, Pisa, Italy, October 1998, pp. 295 – 300.

[17] J. G. Proakis: Digital Communications, McGraw-Hill Education Ltd, 4th Edition, Boston, 2000.

[18] A. Ahmad, M. T. Raza Khan, Z. Kaleem: Uplink Optimal Power Allocation for Heterogeneous Multiuser SIMO SC-FDMA Networks, Electronics Letters, Vol. 52, No. 24, November 2016, pp. 1990 – 1992.

[19] F. A. Orakzai, A. Ahmad, M. T. Raza Khan, M. Iqbal: Optimal Energy-Efficient Resource Allocation in Uplink SC-FDMA Networks, Transactions on Emerging Telecommunications Technologies, Vol. 28, No. 8, August 2017, p. e3153.

[20] A. Ahmad, M. T. Raza Khan: Resource Allocation for SC-FDMA Based Cognitive Radio Systems, International Journal of Communication Systems, Vol. 30, No. 5, March 2017, p. e3046.

[21] A. Ahmad, M. Assaad: Polynomial-Complexity Optimal Resource Allocation Framework for Uplink SC-FDMA Systems, Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM), Houston, USA, December 2011, pp. 1 – 5.

[22] N. Sailakshmi Kumari, P. Kavi Priya, A. Kumar Panigrahy, S. Kumar Tallapalli: Leveraging LSTM Networks for CFO Estimation in MIMO-OFDM System Optimization, Proceedings of the 6th International Conference for Emerging Technology (INCET), Belgaum, India, May 2025, pp. 1 – 6.

[23] T.- H. Vu, S. Kim: Performance Analysis of Full-Duplex Two-Way RIS-Based Systems with Imperfect CSI and Discrete Phase-Shift Design, IEEE Communications Letters, Vol. 27, No. 2, February 2023, pp. 512 – 516.

[24] M. Subha, D. Judson: A Low-Complexity Transceiver Scheme for Joint DFT Pre-Coded DWT SC-FDMA NOMA System Under Dissimilar Power Allocation Strategies, Sādhanā, Vol. 49, No. 3, September 2024, p. 204.

[25] S. U. Rehman, J. Ahmad, A. Manzar, M. Moinuddin: Beamforming Techniques for MIMO-NOMA for 5G and Beyond 5G: Research Gaps and Future Directions, Circuits, Systems, and Signal Processing, Vol. 43, No. 3, March 2024, pp. 1518 – 1548.

[26] R. Magueta, D. Castanheira, A. Silva, R. Dinis, A. Gameiro: Two-Step Hybrid Multiuser Equalizer for Sub-Connected mmWave Massive MIMO SC-FDMA Systems, Proceedings of the 26th European Signal Processing Conference (EUSIPCO), September 2018, Rome, Italy, pp. 822 – 826.

[27] L. Zhang, Y. Wang, W. Tao, Z. Jia, T. Song, C. Pan: Intelligent Reflecting Surface Aided MIMO Cognitive Radio Systems, IEEE Transactions on Vehicular Technology, Vol. 69, No. 10, October 2020, pp. 11445 – 11457.

[28] K. Selvaraj, M. Anandaraj, D. Judson, P. Ganeshkumar, K. Rajkumar: A Low Complexity Near Optimal Signal Detection for Large Scale MIMO SC-FDMA Uplink System, Wireless Personal Communications, Vol. 126, No. 1, September 2022, pp. 231 – 250.

[29] Ishu, N. Kumar: PAPR Reduction in Wavelet Based SC-FDMA Using PTS Scheme for LTE Uplink Transmission, Proceedings of the International Conference on Advances in Computing, Communications and Informatics (ICACCI), Delhi, India, September 2014, pp. 1810 – 1814.

[30] P. Sheeba, P. Muneer, V. P. Thafasal Ijyas, M. Usman, M. Wajid: Equalization Techniques for SC-FDMA Systems Under Radio Imbalances at Both Transmitter and Receiver, Wireless Personal Communications, Vol. 129, No. 4, April 2023, pp. 2563 – 2581.