Equal Gain Combining SC-FDMA Performance over Correlated Shadowed Rice Land Mobile Satellite Channel

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***Abstract*— Single Carrier Frequency Division Multiple Access (SC-FDMA) has shown robustness to multipath fading and similar characteristics to those of Orthogonal Frequency Division Multiple Access (OFDMA). The main advantage of SC-FDMA over OFDMA is its lower Peak to Power Average Ratio (PAPR). Because of this, Single Carrier Frequency Division Multiple Access has been proposed for transmission in Land Mobile Satellite (LMS) Systems. The link level performance of LMS system is diminished by rapid amplitude and phase variations of the received signal. These fluctuations are caused by multipath propagation and attenuation due to shadowing and can be alleviated by the use of diversity at receiver. In this paper, we have investigated SC-FDMA performance for Equal Gain Combining (EGC) diversity over a correlated Shadowed Rice LMS channel, a generalized Rice channel in which the Line of Sight is following Nakagami-m distribution and received echoes following an exponentially decreasing Power Delay Profile. We show that Interleaved SC-FDMA performance is better than Localized SC-FDMA.**

Keywords- OFDMA;SC-FDMA;LOS;LMS;Shadowed Rice.

I. INTRODUCTION

Satellite communication is growing fast in order to follow unpredictable increase in demand for improved quality of service, higher capacity and ubiquitous connectivity. Satellite networks with the terrestrial networks are showing fast and strong development. In this regard, the use of multicarrier modulation and Multiple Input Multiple Output (MIMO) [1] technology are very promising candidates to reduce bandwidth requirement and enhance capacity and data rates. MIMO technology offers many advantages, such as i) Multiuser diversity gain, (ii) Spatial multiplexing gain (iii) Coding gain, and Interference reduction [1].

Orthogonal Frequency Division Multiplexing (OFDM) has demonstrated to be competent technology for wireless communication. The major advantage of OFDM is its relatively simple method of handling frequency selective fading channels which are normally observed in wireless channels [2]. However, OFDM transmission has high Peak to Average Power Ratio (PAPR) which increases the power back up for operation of Linear Power Amplifier. There are many techniques to reduce the OFDM PAPR [3][4] and the outcome of that is DFT Spread OFDM [5].

Single Carrier Frequency Division Multiple Access (SC-FDMA) is a closely related transmission scheme with the same multipath fading mitigation characteristics as that of OFDM [6][7]. Though SC-FDMA has shown worse performance with Rayleigh fading [8], its performance has improved with increase in Line of Sight (LOS) in Rician fading [9].

SC-FDMA performs DFT spreading in the transmitter, before going to Inverse Discrete Fourier Transform (IDFT) [5]. The DFT operation in transmitter helps SC-FDMA to spread the energy of individual modulation symbols over a number of subcarriers in the DFT block. The transmitters in SC-FDMA system use different subcarrier to transmit information symbols. However, they transmit the subcarriers sequentially, instead of in parallel. In relation to OFDM, this arrangement reduces fluctuation in the transmitted waveform. Therefore, SC-FDMA signals have naturally lower PAPR. However, in a cellular system with severe multipath fading, the SC-FDMA signals arrive at the base station with inter symbol interference (ISI). At the receiver, adaptive frequency domain equalization is used to cancel ISI.

Depending on how the DFT spread symbols are mapped onto the subcarriers in the IDFT block, mapping is classified into two types: localized and interleaved. In Localized-SC-FDMA (L-SC-FDMA), each terminal uses a set of adjacent subcarriers to transmit its symbols [10]. In Interleaved-SC-FDMA (I-SC-FDMA), the subcarriers used by the terminals are spread over the entire signal band, and occupied subcarriers are equidistant from each other.

Diversity combining techniques such as Maximal Ratio Combining (MRC), Equal Gain Combining (EGC) and Selection Combining (SC) are used to mitigate fading in wireless channel. It is known that equal gain combing receiver yields similar performance to MRC, with lower implementation complexity. In an EGC combiner, the output of different diversity branches are first co-phased and then weighted equally before combining to give resultant output [11]. Co-phasing is required to avoid signal cancellation.

The EGC performance analysis is found in [12]. A complete summary of most of the linked work is found in [13]. Frequency-Domain (FD) Amplify and Forward (AF) single relay SC-FDMA performance with EGC is studied in [14]. In [15], we studied the Equal Gain combing SC-FDMA performance over unshadowed Rice Land Mobile Satellite (LMS) channel.

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The rest of the paper is organized as follows. Section II presents the system model. Section III describes the channel model used to carry out simulation. In Section IV, simulation results are presented. Finally, Section V provides the conclusion.

II. CHANNEL MODEL

The link level performance of LMS systems strongly depends on the transmission channel between the satellite and the mobile user. The statistical models for narrowband LMS channels can be classified into two types of fading: shadowed and unshadowed Rice fading. When the mobile receiver has a clear path to the satellite it is called unshadowed fading. In case of shadowed fading, the line of sight path is blocked by terrain, vegetation, or human-made structures.

The first shadowed Rice model was proposed by Loo [16], where Line Of Sight (LOS) component follows lognormal distribution. In this paper, we have used the model discussed in [17], where they assumed that the power of LOS component is a gamma random variable. G. L Stuber et al. [18] discussed that the square root of a gamma variable has Nakagami-m distribution.

In the used channel model, the scattered component of the received signal follows Rayleigh distribution and LOS follows a Nakagami-m distribution [17] as follows:

$$P_X(x) = \frac{x}{b_o} exp\left(\frac{-x^2}{2b_o}\right) \quad (1)$$

$$P_Y(y) = \frac{2m^m}{\Gamma(m)\Omega^m} y^{2m-1} exp\left(\frac{-my^2}{\Omega}\right) \quad (2)$$

where $2b_o = \mathrm{E}\,[X^2]$ is the average power of scatter component, $\Gamma()$ is the gamma function, $m = E\,[Y^2]/ Var\,[Y^2] \geq 0$ with $Var[.]$ as the variance, and $\Omega = \mathrm{E}\,[Y^2]$ is the average power of the LOS component. The shadowed Rice PDF [17] in terms of a Nakagami parameters is as follows:

$$P_R(r) = E_Y\left[\frac{r}{b_o} exp\left(\frac{r^2+Z^2}{2b_o}\right) I_O\left(\frac{Z\,r}{b_o}\right)\right] \quad (3)$$

where E_Y is the expectation with respect to Y, and $I_n(.)$ is the nth order modified Bessel's function of the first kind.

In the proposed satellite channel model, a fixed and sufficiently large number of rays are assumed, thus eliminating the need to use a Poisson distribution. Power Delay Profile (PDP) describes the numbers and position of echoes, as well as their average power. In Land Mobile system it is usual to consider an exponential PDP [19] with parameter τ_{avg} such that the scattered received power for lth echo is as follows:

$$P_l = \frac{1}{\tau_{avg}} e^{-\left(\frac{\tau_l}{\tau_{avg}}\right)} \quad (4)$$

For a rural environment, a typical value of τ_{avg} is less than 1 μs and less than 2 μs for a suburban area [20]. The value of τ_{avg} used in this paper is 1.17 μs.

III. SYSTEM MODEL

Figure 1 shows the block diagram of an EGC SC-FDMA transmitter-receiver. The input bits to be transmitted are converted in complex symbols (e.g. BPSK [8] or QAM [8]) using digital modulation techniques. The N_c-point DFT operation converts these complex symbols into precoded complex symbols $\boldsymbol{X_{N_c}}$. The precoded symbols are then mapped on a subset of different allocated subcarriers per user, i.e., N_c out of M sub-carriers in which the total system bandwidth is divided. The mapping can be Interleaved (I-SC-FDMA) or Localized (L-SCFDMA). After subcarrier mapping, a cyclic prefix (CP) is added and complex symbols are transmitted. We assume that CP is long enough so that the non zero echoes are fitted into it.

At the receiver, after the removing the CP, the M-DFT operation converts the received symbol from the time domain to the frequency domain. The received signal is given by

$$\boldsymbol{Y}_n = \boldsymbol{H}_n\boldsymbol{X} + \boldsymbol{\eta}_n \quad (5)$$

where $n \,\epsilon\, \{1,2,..N_R\}$ represents the antenna index, N_R being the number of antennas at the receiver, $\boldsymbol{\eta}_n$ is a noise vector whose entries are i.i.d. complex Gaussian $\mathcal{CN}(0, \mathrm{N}_0)$ and $\boldsymbol{H}_n$ represents the $M \times M$ diagonal matrix whose entries are the channel frequency response as seen by the N_R antennas for each allocated subcarrier [21]. These N_R signals are frequency combined using EGC [21].

$$\boldsymbol{Y} = \frac{\sum_{n=1}^{N_R} \boldsymbol{Y}_n * exp(-j * angle(diag(\boldsymbol{H}_n)))}{\sum_{n=1}^{N_R} |\boldsymbol{H}_n|} \quad (6)$$

after taking N_c-IDFT of $\boldsymbol{Y}$, it is given to the detector. The output of detector is estimate of the input bits.

IV. PERFORMANCE RESULTS

In this section, simulation results are carried to evaluate BER performance for the SIMO (1× 2) EGC I-SC-FDMA and L-SC-FDMA over shadowed Rice LMS channel. The parameters used for simulation are shown in Tables I and II.

TABLE I. SHADOWED RICE CHANNEL PARAMETERS FOR DIFFERENT FADING I

	b_o	m	Ω
Light shadowing	0.158	19.4	1.29
Heavy shadowing	0.063	0.739	8.97e-04
Average shadowing	0.126	10.1	0.835

Different shadowed conditions, Heavy, Light and Average are considered while carrying out the simulation. The SIMO (1× 2) EGC SC-FDMA performance has been evaluated for different antenna correlation factor, number of antennas at receiver, and allocated subcarriers.

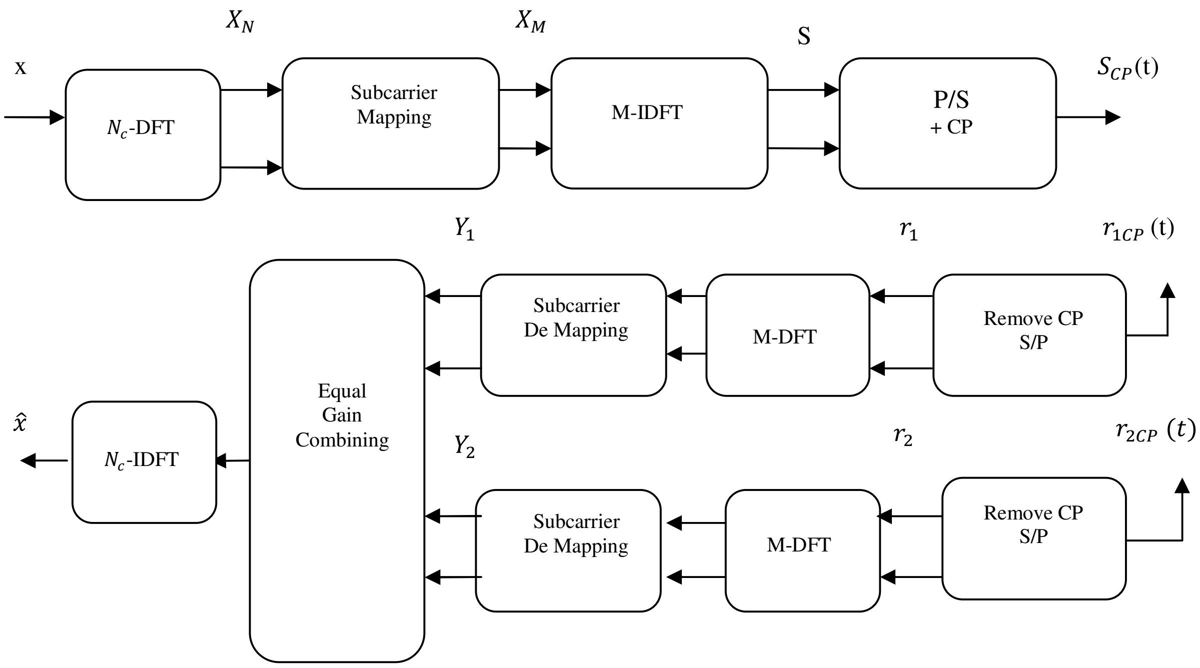

Figure 1. EGC SC-FDMA Transmitter Receiver scheme

TABLE II SIMULATION PARAMETERS

FFT Size	1024
Modulation Techniques	QPSK
Carrier Frequency	2.00GHz
System Bandwidth	20MHz
Channel model	Satellite LMS with exponential PDP
Number of Antennas Used	2, 4
Equalizers used	EGC
τ_{avg}	1.17 μs

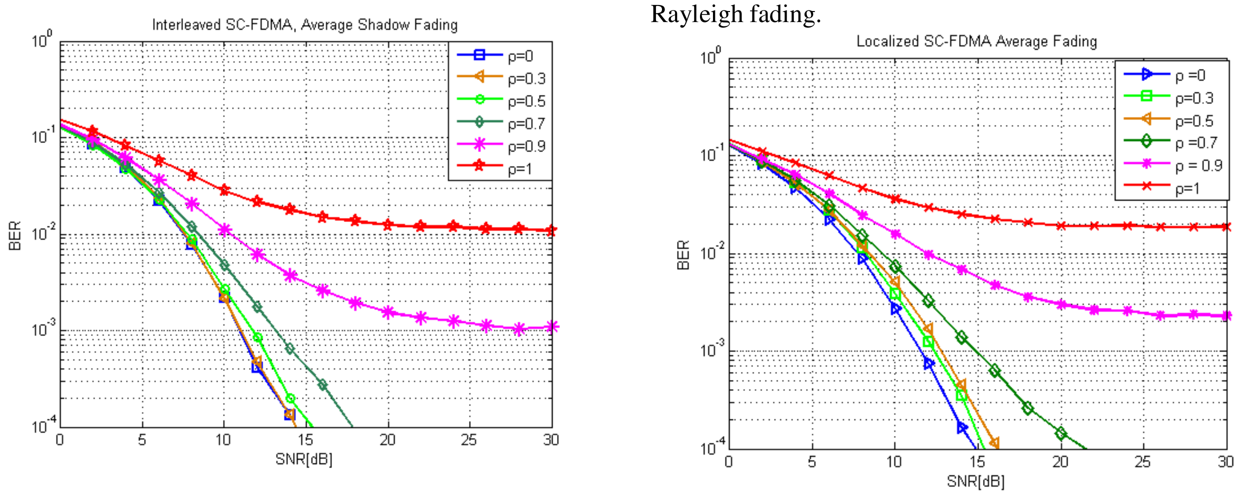

Figure 2: BER performance of Interleaved SC-FDMA and Localized SC-FDMA for different antenna correlation factor: Average Shadow fading

Figures 2 and 3 show the BER performance of Interleaved SC-FDMA and Localized SC-FDMA for Average and Light fading. Interleaved SC-FDMA performance over Average and Light fading is better than that of Localized SC-FDMA. In light fading, the LOS component has more power than the multipath component. The light and average shadowed Rician distribution can be represented by the normal Rician distribution with a Rice factor of 5.3 and 4.1 dB, respectively [22].

Figure 4 shows the BER performance of Interleaved SC-FDMA for Heavy fading. In case of Heavy fading the Line of Sight component has very low power, it behaves as good as Rayleigh fading.

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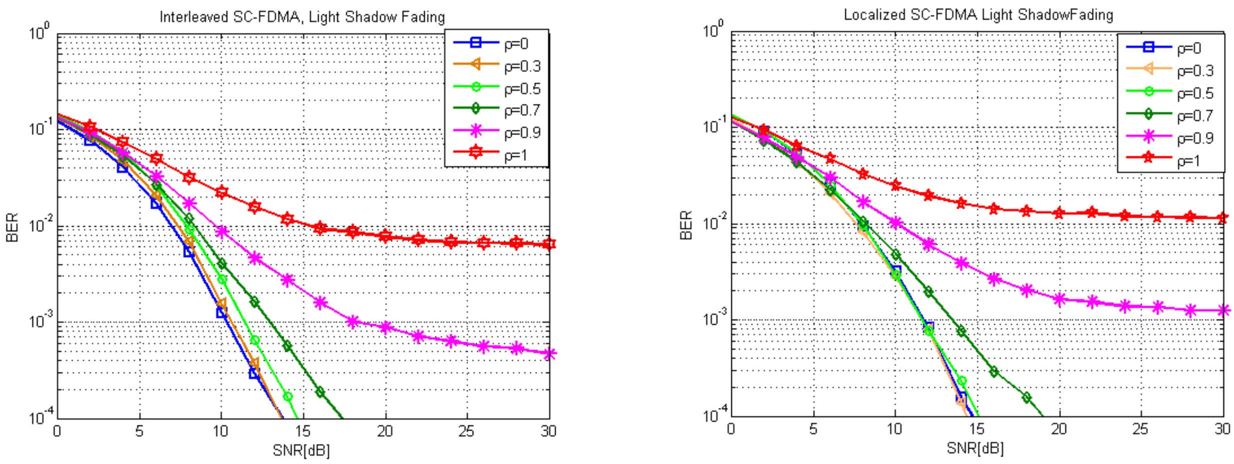

Figure 3: BER performance of Interleaved SC-FDMA and Localized SC-FDMA for different antenna correlation factor: Light Shadow fading

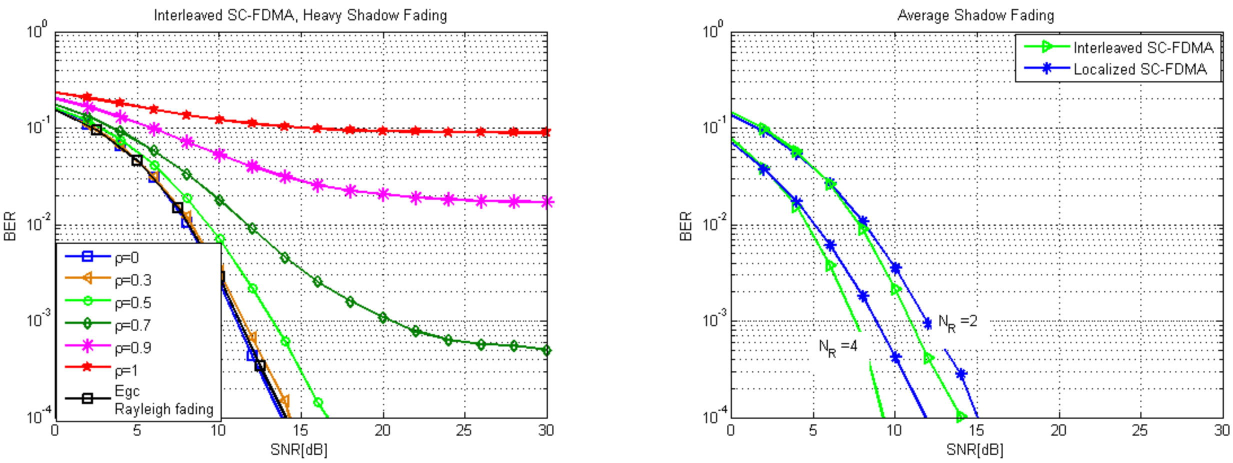

Figure 4: BER performance of Interleaved SC-FDMA for different antenna correlation factor and different antennas at receiver: Heavy & Average Shadow fading

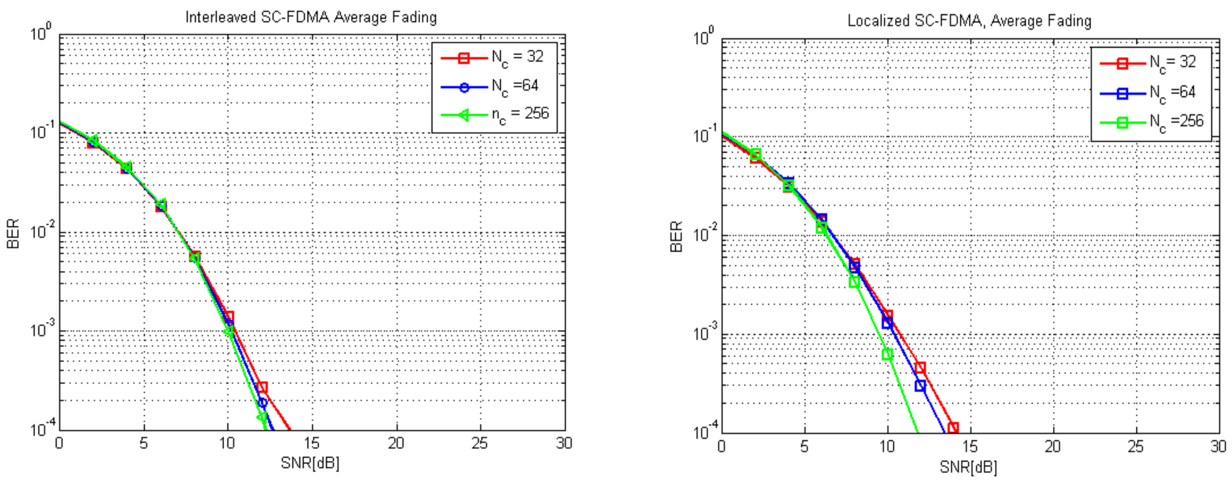

Figure. 5: BER performance of Interleaved SC-FDMA and Localized SC-FDMA for different allocated subcarriers: Average Shadow fading

Results have shown that performance is similar below certain antenna correlation threshold, for Light fading threshold is 0.5. Note that the existence of LOS (quite powerful for Light fading) always provokes certain correlation between signals received at different antennas, thus the lack of spatial correlation does not further improve the BER performance. The results in Figure 4 shows that a higher number of receiving antennas improve BER performance over Average fading, as expected.

In Figure 5, the performance for different number of allocated subcarriers over Average fading shows that BER performance is not greatly modified by N_c.

V. CONCLUSION

In this paper, we have investigated BER performance of SIMO (1×2) EGC for Interleaved and Localized SC-FDMA over shadowed Rice LMS channel where LOS component follows Nakagami-m distribution. The performance is studied under light, average and heavy fading. It is observed that, as expected, in all three cases EGC diversity shows better performance as compared to SISO SC-FDMA. In case of Heavy fading, the performance is worse because LOS component has low power. The antenna correlation effect in all three types of fading shows that the more antenna correlation, the more errors at the detection. However, existence of LOS always provokes certain correlation between signals received at different antennas thus improvement for lower spatial correlation or using more antennae is not high. In general, Interleaved SC-FDMA BER performance is better than Localized SC-FDMA in shadowed Rice fading. The Interleaved SC-FDMA can be best transmission scheme for uplink satellite communication with EGC receiver diversity technique. Further, it is recommended to study the performance of MIMO SC-FDMA over Land Mobile Satellite channel.

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REFERENCES

[1] P. Arapoglou, K. Liolis, M. Bertinelli, A. Panagopoulos, P. Cottis, and R. Gaudenzi, "MIMO Over Satellite: A Review," IEEE Communications Surveys and Tutorials, Vol. 13. No. 1, May 2010, pp. 27-51

[2] J. Bingham. "Multicarrier modulation for data transmission: An idea whose time has come," IEEE Communication Magazine, May 1990, pp. 5-14

[3] P. Eetvelt, G. Wade, and M.Tomlinson, "Peak to average power reduction for OFDM schemes by selective scrambling," in Electronic Letters, Vol. 32, Oct. 1996,1963-1964

[4] Y. Rahmatallah, N. Bouaynaya, and S. Mohan "Bit Error Rate Performance of Linear Companding Transforms for PAPR Reduction in OFDM Systems," in IEEE Global Communications Conference (GLOBECOM 2011), Houston, Texas, December 2011, pp. 1-5

[5] M. Nisar, H. Nottensteiner, and T. Hindelang, On performance limits of DFT spread OFDM systems," Mobile and Wireless C ommunications Summit, 2007, 16th IST, July 2007, pp. 1-4

[6] A. Czylwik, "Comparision between adaptive OFDM and Single Carrier modulation with frequency domain equalization," in Proc. Vehicular Technology Conference 1997 Phoenix, AZ, vol. 2, May 1997, pp.865-869

[7] H. Sari, G Karam, and I. Jeanclaude, "Transmission techniques for digital terrestrial TV broadcasting," IEEE Commun. Mag., vol. 33, no. 2, pp. Feb. 1995, pp. 100-109

[8] J. Sánchez-Sánchez, "Analysis of SC-FDMA and OFDMA Performance over Fading Channels," Ph.D. dissertation, Universidad de Málaga (Spain), May 2011. [Online]. Available: http://hdl.handle.net/ 10630/4689

[9] J. Gangane, M. Aguayo-Torres, J. Sánchez-Sánchez, and U. Fernández-Plazaola, "SC-FDMA Performance over Rician Channel," Proc. 6th IEEE International Conference on Broadband and Biomedical Communications (IB2Com), November 2011, Melbourne, Australia, pp. 91-96

[10] U. Sorger, I. Broeckan, and M. Schnell, "IFDMA- A New Spread Spectrum Multiple Access Scheme, Multicarrier Spread Spectrum," Kulwer, 1997, pp. 111-118

[11] A. Annamalai, C. Tellambura, and V. Bhargava, "Equal –gain diversity reciver performance in wireless channels," IEEE Trans. Communications, Vol. 48, Oct. 2000, pp. 1732-1745

[12] N. Beaulieu and A. Abu-Dayya, "Analysis of equal gain diversity on Nakagami fading channels," IEEE Trans. Commun. Vol.39, No. 2, Feb. 1991, pp.225-234

[13] M. Simon and M. Alouni, Digital Communication over Fading Channels, 2nd ed., New York:,Wiley, 2004

[14] J. Zang, L. Yang, and I. Hanzo, "Multi –user performance of the amplify and forward single relay assisted SC-FDMA uplink," in Proc. IEEE Vehicular Technology Conference 2009 Fall, Sept. 2009, pp.1-5

[15] J. Gangane, M. Aguayo-Torres, J. Sanchez, and S. Wagh, "Equal Gain Combining (EGC) SC-FDMA Performance over Land Mobile Satellite (LMS) Rice Fading Channel," Proc. IEEE International Conference on Computational Intelligence and Computing Research (IEEE ICCIC), Dec. 2012, Coimbatore, India, pp.1-5

[16] C. Loo, "A statistical model for a land mobile satellite link," IEEE Trans. Veh. Technol, Vol. 34, August 1985, pp. 122-127

[17] A. Abdi, W. Lau, M. Alouni, and M. Kaveh, "A new simple model for land mobile satellite channels: first-and second order statistics," IEEE Trans. Wireless Comm., Vol. 2, No. 3, May 2003, pp. 519-528

[18] G. L. Stuber, Principles of Mobile Communication, Boston, MA: Kluwer, 1996

[19] F. Fontan et al, M. Castro, J. Kunisch, J. Pamp, E. Zollinger, S. Buonomo, P. Baptista, and B. Arbesser, "A versatile framework for a narrow and wide band statistical propagation model for the LMS channel," IEEE Trans. Broadcasting, Vol. 43, Dec.1997, pp.431-458

[20] J. Rees, "Measurements of the wide band radio channel characteristics for rural, residential, and subrurban areas," IEEE Trans. Veh., Technol., Vol. 36, Feb. 1987, pp. 2-6

[21] A. Goldsmith, Wireless Communications, Cambridge University Press, 2005

[22] D. Richard, V. Nee, S. Howard, and R. Prasad, "Direct –Sequence Spread Spectrum in a Shadowed Rician Fading Land Mobile Satellite Channel," IEEE Journal on Selected Areas in Communications, Vol.10, No. 2. February 1992, pp. 350-357