

Variable Splitting Transmission in Multi-Relay Cooperative Communications for SC-FDMA

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Abstract—In recent years, cooperative communications are widely studied. Cooperative communications can obtain the space diversity as multiple-input multiple-output (MIMO) systems. Moreover, the multi-relay cooperative communications can improve the system performance by using several relay nodes. In MIMO systems, the optimum packet splitting method has been proposed to obtain more strongly diversity. However, the optimum splitting method is not proposed in the multi-relay cooperative communications. Therefore, in this paper, we propose the optimum packet splitting method in the multi-relay cooperative communications.

I. INTRODUCTION

In wireless communication systems, a long-term evolution (LTE)-Advanced is standardized to achieve a high data rate and high quality multimedia services as 4th generation (4G) [1]. In a LTE-Advanced, single carrier frequency division multiple access (SC-FDMA) has been adopted in the uplink communication, and orthogonal frequency division multiple access (OFDMA) has been adopted in the downlink communication [2]. SC-FDMA can achieve a low peak average power ratio (PAPR) compared with OFDMA. Since a low PAPR of SC-FDMA can reduce the cost and the power consumption of communication, SC-FDMA is suitable transmission method for the uplink communication.

In recent years, cooperative communications are widely studied [3]. Cooperative communications use the relay node except the source and destination nodes. By using the relay node, cooperative communications can obtain the space diversity as multiple-input multiple-output (MIMO) systems. Moreover, the multi-relay cooperative communications can improve the system performance by using several relay nodes since they obtain more strongly diversity [4], [5]. However, if the channel condition of relays is bad, the system performance is degraded. To solve this problem, the optimum packet splitting has been proposed in MIMO systems [6]. The optimum packet splitting method splits the packet by considering the channel condition and sends from each transmit antenna. As a result, since the optimum packet splitting method obtains more strongly diversity, it can improve the system performance. However, [4] and [5] do not consider the optimum packet splitting. Therefore, we propose the optimum packet splitting in the multi-relay cooperative systems. Also, cooperative communications can improve the system performance by using the power allocation

(PA) [7]-[9]. This method is also effective in the multi-relay cooperative communications [8]. Therefore, [9] has adopted the waterfilling power allocation (WF/PA) method. However, the WF/PA method requires large feedback information (FBI) since it has to feedback the channel state information (CSI) of each sampling points in a frequency domain. To solve these problems, in this paper, we propose the optimum packet splitting method based on the time domain CSI in the multi-relay cooperative communication. This paper is organized as follows. In Section II, we present the system model. Then, we describe the proposed variable splitting method in Section III. In Section IV, we show the computer simulation results. Finally, the conclusion is given in Section V.

II. SYSTEM MODEL

In this paper, we assume the multi-relay cooperative communications as shown in Figure 1. Here, we define that SD is the link between the source and destination nodes, SR is the link between the source and relay nodes, RD is the link between the relay and destination nodes, and SRD is the link between the source, relay, and destination nodes, respectively.

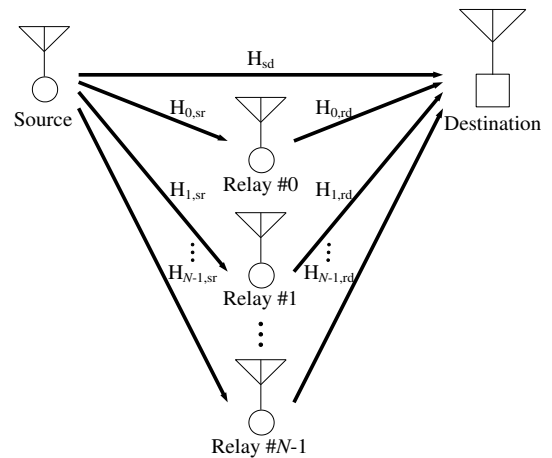


Fig. 1. Multi-relay cooperative communications.

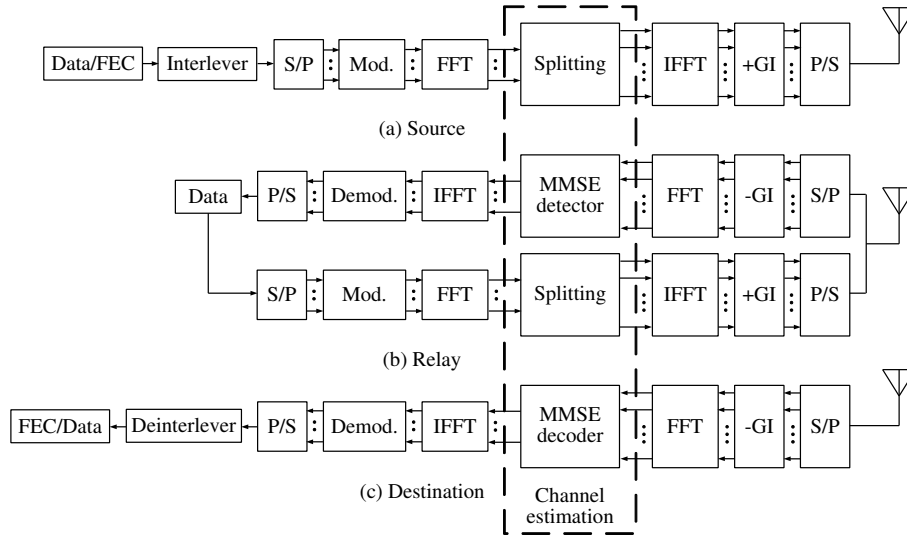


Fig. 2. Proposed system.

A. Channel Model

We assume that a propagation channel consists of L discrete paths with different time delays. The impulse response $h_n(\tau, t)$ for the n th node is represented as

$$h_n(\tau, t) = \sum_{l=0}^{L-1} h_{n,l}(t) \delta(\tau - \tau_{n,l}), \quad (1)$$

where $h_{n,l}$, $\tau_{n,l}$ are the complex channel gain and the time delay of the l th propagation path for the n th node, $\sum_{l=0}^{L-1} E|h_{n,l}|^2 = 1$, and $E|\cdot|$ denotes the ensemble average operation, respectively. The channel transfer function $H_n(f, t)$ is the Fourier transform of $h_n(\tau, t)$ and is given by

$$\begin{aligned} H_n(f, t) &= \int_0^\infty h_n(\tau, t) \exp(-j2\pi f\tau) d\tau \\ &= \sum_{l=0}^{L-1} h_{n,l}(t) \exp(-j2\pi f\tau_{n,l}). \end{aligned} \quad (2)$$

B. Source Node

The source node block diagram of the proposed system is shown in Fig. 2(a). Firstly, the coded data is modulated, and is performed with interleaving. After the N_c points IFFT operation, the time domain transmitted signal for the n th node $s_n(t)$ can be expressed as

$$s_n(t) = \sqrt{\frac{2E_s}{T_s}} \sum_{k=0}^{N_c-1} u_n(k) \exp\left(j2\pi k \frac{t}{N_c}\right), \quad (3)$$

where N_c is the number of sampling points, T_s is the effective symbol length, and E_s is the average transmission power, respectively. For Eq. (3), by using the N_c points FFT operation, the frequency domain signal $u_n(k)$ is given by

$$u_n(k) = \sqrt{\frac{2E_s}{N_c}} \sum_{t=0}^{N_c-1} d_n(t) \exp\left(-j2\pi k \frac{t}{N_c}\right), \quad (4)$$

where $d_n(t)$ is the original signal for the n th node. From Eq. (3), the proposed method splits the packet as shown in Fig. 3. Here, the number of total data symbols N_d is defined as

$$N_d = N_D + \sum_{i=0}^{N-1} N_{i,R}, \quad (5)$$

where N_D is the number of data symbols for SD , $N_{i,R}$ is the number of data symbols for i th SRD , and N is the number of relay nodes, respectively. For the optimum packet splitting, we explain in section III. In general, the guard interval (GI) is inserted in order to eliminate the inter-symbol interference (ISI) due to a multipath fading, and hence, we have

$$T = T_s + T_g, \quad (6)$$

where T_g is the GI length.

C. Relay Node

The relay node structure is illustrated in Fig. 2(b). The received signal for the n th relay node $\hat{r}_n(t)$ can be expressed as

$$\hat{r}_n(t) = \int_{-\infty}^{\infty} h_{n,sr}(\tau, t) s_n(t - \tau) d\tau + n_n(t), \quad (7)$$

where $n_n(t)$ is additive white Gaussian noise (AWGN) with a single sided power spectral density of N_0 . After removing the GI, by using the N_c points FFT operation, Eq. (7) is rewritten as

$$\hat{r}_n(k) = \sqrt{\frac{2E_s}{T_s}} H_{n,sr}(k) u_n(k) + \hat{n}_n(k), \quad (8)$$

where $\hat{n}_n(k)$ is AWGN noise with zero-mean and a variance of $2N_0/T_s$. By using the minimum mean square error (MMSE) equalization, the detected signal of Eq. (8) $\hat{u}_n(k)$ is given by

$$\hat{u}_n(k) = \hat{r}_n(k) \cdot \omega_{n,sr}(k), \quad (9)$$

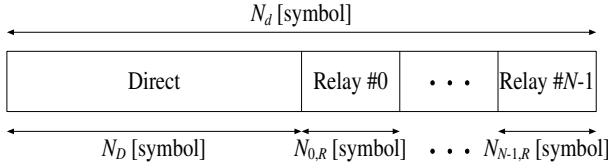


Fig. 3. Packet splitting.

where $\omega_{n,sr}(k)$ is the MMSE weight for SR . After the detection, the detected signal $\hat{u}_n(k)$ is also modulated and transmits to the destination by using decode-and-forward (DF).

D. Destination Node

The destination node structure is illustrated in Fig. 2(c). The received signal $r(t)$ can be expressed as

$$\begin{aligned} r(t) &= r_0(t) + \sum_{n=0}^{N-1} r_n(t) + n(t) \\ &= \sum_{n=0}^N \int_{-\infty}^{\infty} h_n(\tau, t) s_n(t - \tau) d\tau + n(t), \end{aligned} \quad (10)$$

where $r_0(t)$ is the received signal for SD , $r_n(t)$ is the n th received signal for RD , and $n(t)$ is AWGN, respectively. As same Eq. (8), Eq. (10) is rewritten as

$$\tilde{r}(k) = \sum_{n=0}^N \sqrt{\frac{2E_s}{T_s}} H_n(k) u_n(k) + \hat{n}(k), \quad (11)$$

where $\hat{n}(k)$ is AWGN noise. By using the MMSE equalization, the detected signal of Eq. (11) $\tilde{u}_n(k)$ is given by

$$\tilde{u}_n(k) = \begin{cases} r(k) \cdot \omega_{sd}(k) & \text{for } SD \\ r(k) \cdot \omega_{n,rd}(k) & \text{for } RD, \end{cases} \quad (12)$$

where $\omega_{sd}(k)$ and $\omega_{n,rd}(k)$ are the MMSE weights for SD and n th RD , respectively. Finally, by using the N_c points IFFT operation, the desired signal $\tilde{d}_n(t)$ is given by

$$\tilde{d}_n(t) = \sqrt{\frac{2E_s}{N_c}} \sum_{k=0}^{N_c-1} \tilde{u}_n(k) \exp\left(j2\pi k \frac{t}{N_c}\right). \quad (13)$$

E. MMSE Equalization

In this paper, we assume the perfect channel estimation. In this case, the MMSE weight $\omega_n(k)$ is given by

$$\omega_n(k) = \frac{H_n^*(k)}{|H_n(k)|^2 + \sigma_n^2(k)}, \quad (14)$$

where $(\cdot)^*$ is a complex conjugate and σ_n^2 is the noise power, respectively [11].

III. PROPOSED VARIABLE SPLITTING METHOD

A. Waterfilling Power Allocation (WF/PA)

The waterfilling power allocation (WF/PA) method has been proposed to improve the system performance [9], [10]. The WF/PA method mitigates the deep faded channel by using the

optimum power assignment. The optimum power of the k th sampling point for the n th node $P_n(k)$ is given by

$$P_n(k) = \begin{cases} \mu_n - \frac{1}{|H_n(k)|^2} & \text{for } \mu_n \geq \frac{1}{|H_n(k)|^2} \\ 1 & \text{otherwise,} \end{cases} \quad (15)$$

where the cutoff SNR level μ_n is

$$\mu_n = \frac{1}{N_c} \sum_{k=0}^{N_c-1} \frac{1}{|H_n(k)|^2}. \quad (16)$$

From Eq. (15), the WF/PA method can improve the system performance. However, the WF/PA method requires large FBI. To mitigate this problem, we propose the variable splitting method.

B. Proposed Variable Splitting Method

The proposed variable splitting method is performed with the time domain CSI. For the time domain CSI, the amplitudes are constant. From this characteristic, since FBI of the proposed method becomes only one, the proposed method can reduce FBI compared with the WF/PA method.

Next, we explain the proposed method. The output signal X due to a Rayleigh fading is expressed as

$$X = X_c + jX_s, \quad (17)$$

where X_c is a real part and X_s is a imaginary part, respectively [12]. From Eq. (17), the amplitude of X is given by

$$|X| = \sqrt{X_c^2 + X_s^2}. \quad (18)$$

By using Eq. (18), the proposed method is performed. Firstly, we define the amplitude for SD (λ_D) as

$$\lambda_D = |X_{SD}|, \quad (19)$$

where X_{SD} is the output signal due to a Rayleigh fading for SD . Also, the amplitude for i th SRD ($\lambda_{i,R}$) is defined as

$$\lambda_{i,R} = \sqrt{(1 - \alpha)|X_{i,SR}|^2 + \alpha|X_{i,RD}|^2}, \quad (20)$$

where $X_{i,SR}$ and $X_{i,RD}$ are the output signals due to a Rayleigh fading for i th SR and i th RD , and α is the selection parameter for SRD , respectively. Next, we decide the number of data symbols N_D and $N_{i,R}$ for SD and i th SRD . Firstly, the proposed method decides the number of data symbols for SD (N_D) as

$$N_D = N_d \times \left\lfloor \sum_{j=0}^{N-1} \frac{\gamma \lambda_D}{\lambda_D + \lambda_{j,R}} \right\rfloor, \quad (21)$$

where γ is the selection parameter for SD and SRD and $\lfloor x \rfloor$ stands for the integer and closer to x , respectively. For the parameters α and γ , we decide them by using the computer simulation in section IV. After choosing N_D , the proposed method decides $N_{i,R}$. The number of data symbols for i th SRD is given by

$$N_{i,R} = (N_d - N_D) \times \left\lfloor \sum_{j=0}^{N-1} \frac{\lambda_{i,R}}{\lambda_{j,R}} \right\rfloor. \quad (22)$$

By using Eqs. (21) and (22), the proposed method can achieve the optimum packet splitting.

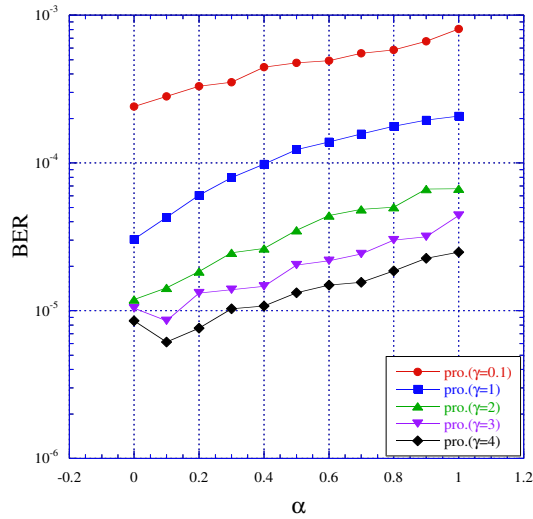


Fig. 4. The BER versus parameter α for $\gamma = 0.1, 1, 2, 3$, and 4 with $E_b/N_0 = 20$ dB at Doppler frequency of 5 Hz.

IV. COMPUTER SIMULATION RESULTS

In this section, we show the performance of the proposed method. Figure 2 shows a simulation model of the proposed system. On the source node, the data stream is encoded. Here, convolutional codes (rate $R = 1/2$, constrain length $K = 7$) with interleaving are used. The coded bits are QPSK modulated. After serial to parallel (S/P) converted, the FFT spreading operation is performed. By using the IFFT operation, the SC-FDM time domain signal is generated and is inserted a guard interval (GI). The SC-FDM time domain signal is split with Eqs. (21) and (22), and is transmitted to the relay and destination nodes. In this simulation, we assume that the channel estimation is the perfect. Moreover, the SC-FDM symbol period is $2 \mu s$, the GI length is $125 ns$, the path separation is $T_{path} = 37 ns$, and the maximum Doppler frequency is 5 Hz. In the relay node, the received signal is detected as Eq. (9). After the detection, the detected signal is modulated again, and is transmitted to the destination node. In this paper, we assume the decoded-and-forward (DF). In the destination node, all received signals are combined, and are

TABLE I
SIMULATION PARAMETERS.

Data modulation	QPSK
Data detection	Coherent
Symbol duration	$2 \mu s$
Number of data symbols	80
Number of sampling points	48
Number of relay nodes	0, 2
Guard interval	6 sample times
Fading	2 path Rayleigh fading
Doppler frequency	5 Hz
FEC	Convolutional code ($R = 1/2, K = 7$)

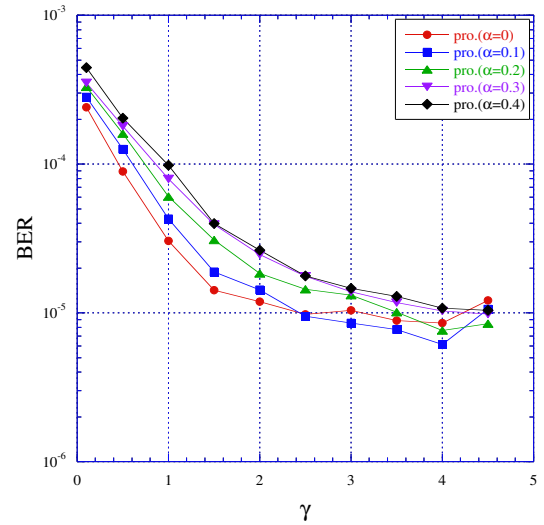


Fig. 5. The BER versus parameter γ for $\alpha = 0, 0.1, 0.2, 0.3$, and 0.4 with $E_b/N_0 = 20$ dB at Doppler frequency of 5 Hz.

S/P converted. After removing the GI, the parallel sequences are passed to the FFT operator and convert the signal back to the frequency domain. The frequency domain data signal is detected by using the MMSE equalization. After the detection, the detected signal is converted to the time domain signal by the IFFT operation. And then, the total bits are decoded by using the Viterbi soft decoding algorithm. The packet consists of $N_d = 80$ data symbols. Table I shows the simulation parameters.

Firstly, we decide the optimum value of the parameters α and γ . Fig. 4 shows the BER versus parameter α for $\gamma = 0.1, 1, 2, 3$, and 4 with $E_b/N_0 = 20$ dB at Doppler frequency of 5 Hz. From the simulation result, when α is small and γ is large, the proposed method shows the good BER performance. Moreover, when $\alpha = 0.1$ and $\gamma = 4$, the proposed method shows the best BER performance. Fig. 5 shows the BER versus parameter γ for $\alpha = 0, 0.1, 0.2, 0.3$, and 0.4 with $E_b/N_0 = 20$ dB at Doppler frequency of 5 Hz. From the simulation result, when α is small and γ is large, the proposed method shows the good BER performance. Moreover, when $\alpha = 0.1$ and $\gamma = 4$, the proposed method shows the best BER performance as same Fig. 4. On the other hand, when γ is greater than 4 , the proposed method shows the bad BER performance. From Figs. 4 and 5, we decide the parameters as $\alpha = 0.1$ and $\gamma = 4$.

Next, we show the BER performance of the proposed method. Fig. 6 shows the BER of the conventional and proposed methods at Doppler frequency of 5 Hz. Firstly, the BER of the conventional method of $N_D = 40$ and $N_{1,R} = N_{2,R} = 20$ shows about 4 dB gain compared with $N = 0$. This is because the conventional method of $N_D = 40$ and $N_{1,R} = N_{2,R} = 20$ obtains the space diversity by using two relay nodes. Next, the BER of WF/PA shows about 2 dB gain compared with $N_D = 40$ and $N_{1,R} = N_{2,R} = 20$. This is because the WF/PA method mitigates the deep faded channel by using the optimum power assignment. However, the WF/PA

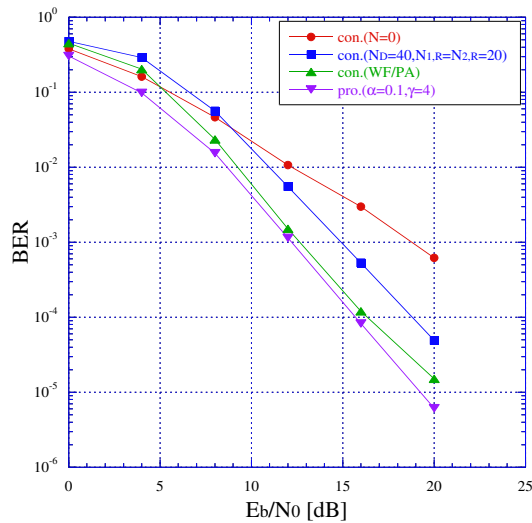


Fig. 6. The BER of conventional and proposed methods at Doppler frequency of 5 Hz.

method requires large FBI. The proposed method reduces FBI compared with the WF/PA method. Moreover, the BER of the proposed method shows about 2 dB gain compared with the WF/PA method. This is because the proposed method obtains the space diversity and coding gains by using the optimum packet splitting. Therefore, the proposed method is effective, and shows the best BER performance.

V. CONCLUSION

In this paper, we have proposed the variable packet splitting method in the multi-relay cooperative communications. The proposed method obtains the space diversity by using the multi-relay cooperative communications. Moreover, since the proposed method uses the error correcting code and interleaving, obtains also the coding gain. However, if the channel condition of relays is bad, the system performance is degraded. Therefore, the proposed method splits the packet to obtain the space and coding gains. Moreover, the proposed method uses the selection parameters α and γ to obtain the maximum gains. As a result, the proposed method obtains the maximum coding gain due to the space diversity. From the simulation results, the proposed method has decided the optimum value of selection parameters α and γ , and achieved the best BER performance.

REFERENCES

- [1] S. Abeta, "Toward LTE commercial launch and future plan for LTE enhancements (LTE-Advanced)", Proc. of ICCS2010, pp. 146-150, Nov. 2010.
- [2] F. Adachi, H. Tomeba, and K. Takeda, "Frequency-domain equalization for broadband single-carrier multiple access", IEICE Trans. on Commun., vol. E92-B, no. 5, pp. 1441-1456, May 2009.
- [3] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior", IEEE Trans. on Info. Theory, vol. 50, no. 12, pp. 3062-3080, Dec. 2004.
- [4] T. Q. Duong and H. J. Zepernick, "Hybrid decode-amplify-forward cooperative communications with multiple relays", Proc. of WCNC2009, PHY11.2, pp. 1-6, April 2009.

- [5] S. Chen, W. Wang, and X. Zhang, "Performance analysis of multiuser diversity in cooperative multi-relay networks under rayleigh-fading channels", IEEE Trans. on Wireless Commun., vol. 8, no. 7, pp. 3415-3419, July 2009.
- [6] S. Sun, T. Hunziker, J. Cheng, M. Taromaru, and T. Ohira, "Optimal frame splitting for downlink MIMO channels with distributed antenna arrays", IEEE Trans. on Vehi. Tech., vol. 57, no. 6, pp. 3848-3854, Nov. 2008.
- [7] B. Wang and D. Zhao, "Optimum power distributed for uplink channel in a cooperative wireless CDMA network", Proc. of ICC'08, pp. 4795-4801, May 2008.
- [8] Y. Li, B. Vucetic, Z. Zhou, and M. Dohler, "Distributed adaptive power allocation for wireless relay networks", IEEE Trans. on Wireless Commun., vol. 6, no. 3, March 2007.
- [9] Y. Ida, C. Ahn, T. Kamio, H. Fujisaka, K. Haeiwa, T. Omori, and K. Hashimoto, "Optimum splitting transmission in multi-relay cooperative communications for WF/PA-SC-FDMA", IEICE Tech. Rep., CS2011-127, pp. 157-160, March 2012.
- [10] M. Nouné and A. Nix, "Performance of SC-FDMA with transmit power allocation and frequency-domain equalization", Proc. of PIMRC2010, pp. 852-857, Sep. 2010.
- [11] Y. Ida, C. Ahn, T. Kamio, H. Fujisaka, and K. Haeiwa, "Throughput performance enhancement for MUDiv/OFDMA using MMSE equalization without guard interval", Journal of Selected Area in Telecommun., vol. 2, no. 5, pp. 74-80, May 2011.
- [12] C. Xiao, Y. R. Zheng, and C. Beaulieu, "Statistical simulation models for rayleigh and rician fading", Proc. of ICC'03, pp. 3524-3529, May 2003.