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Research on Cooperative Diversity in Mobile Satellite Communication System

***Abstract*:** *In order to improve the system performance, the cooperative diversity technology was been adopted to obtain the diversity gains in mobile satellite communication system. First, the feasibility of cooperative diversity in mobile satellite communication system was analyzed. Second, we present a satellite mobile cooperative communication system model and derive two generalized error probability expressions with CRC (Cyclical Redundancy Check) or not. We also derive and simulate SER of the proposed system over different satellite mobile channels. Last, symbol-error-rate (SER) performance analysis is provided for a decode-and-forward cooperative scheme in mobile satellite communication system. The results show that the analytical results are in great accordance with the ones obtained by simulation. Also, it was shown that, whether or not adopt CRC depends on the channel link quality between the source node and the relay node.*

Streszczenie. *W celu poprawy parametrów systemu komunikacyjnego zaadaptowano technologię kooperacyjne różnorodności. Przeanalizowano wykonalność kooperacyjnej różnorodności w systemach mobilnych komunikacji satelitarnej. Następnie określono błędy prawdopodobieństwa w systemach z CRC I bez CRC. Analizowano także parametr SER.* ***(Badania kooperacyjnej różnorodności w mobilnym systemie komunikacji satelitarnej)***

Keywords: Satellite communication; Cooperative diversity; Detect-and -Forward
Słowa kluczowe: komunikacja satelitarna, różnorodność koopreracyjne

1 Introduction

The wireless channel in mobile satellite communication is a typical fading channel. To obtain reliable communications, there is a significant need for method of combating detrimental effects in this wireless fading channel. Most of the current existed mobile satellite systems use the convolution coding and interleave techniques to overcome the effects of the fading; some of them also use diversity reception techniques, such as Globalstar system [1]. Recently, the cooperative diversity transmission technique has attracted considerable research attention as it is capable of significantly improving the performance of wireless communication systems. Several cooperation strategies with different relaying techniques, including amplify-and-forward (AF), decode-and-forward (DF), and selective relaying, have been studied in Laneman et al.'s seminal paper [2]. The performance analysis of symbol-error-rate (SER) for DF in wireless communication is studied in [3].The outage probability of a DF relay system in Rician fading environment is presented in [4]. In [5], the authors derived a cooperative diversity scheme for mobile satellite multimedia broadcasting systems. The performance of DF over fading channels has long been of interest.

In this paper, we present a satellite mobile cooperative communication system which adopting decode-and-forward cooperative scheme in the relay node. Then, we derive two generalized error probability expressions with CRC (Cyclical Redundancy Check) or not. We also derive and simulate SER performance of the proposed system over various satellite mobile channels, which the channel between the source node and the relay node is Gauss channel or Rayleigh channel, and the other channels are independent identically distributed Rayleigh channels, Rician channels or shadowed Rician channels. The results show that the analytical results are in great accordance with the ones obtained by simulation. Also, it was shown that, whether adopt CRC or not depends on the channel link quality between the source node and the relay node.

2 Feasibility analysis

A wealth of satellite resources and satellite ISLs are the key factor for application of cooperative diversity in mobile satellite communication. In order to realize cooperative diversity in mobile satellite communication system, the users need to connect to several satellites at the same time, then the system of multi-satellite constellation have a certain coverage requirements. Here A 48 polar-orbiting satellite constellation system was presented as an example for analysis. The performance of its coverage as shown in Fig.1. From the figure we can see that the global double-satellite coverage rate is more than 60%, 30^0latitudes of double-satellite coverage rate is more than 80%, 50^0 latitudes of double-satellite coverage rate is up to 100% coverage. And 48 polar orbiting satellite constellation system of six orbital planes, each orbital plane has eight satellites. In addition to the same orbit plane of the two adjacent satellites can be used ISLs ,the different orbital plane of the adjacent satellite, as long as their rate of change of angle, the rate of change of distance, time delay rate of change must meet the requirements of still can be established between different orbit ISLs. Therefore, from the analysis above, the application of cooperative diversity in mobile satellite communication is totally feasible.

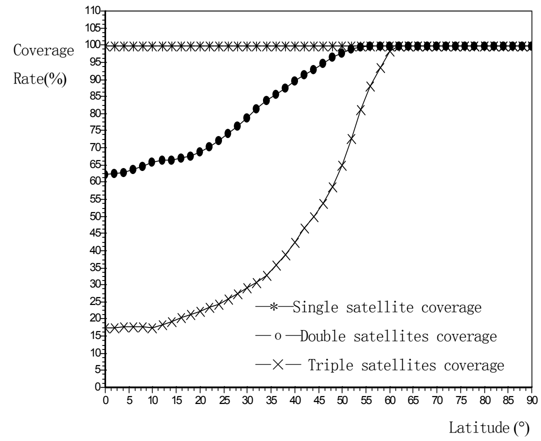

Fig.1 . The coverage of 48 polar-orbit constellation system

3 System model

The mobile satellite communication system, such as Iridium, is abundant in satellite resources and there are some inter-satellite links. The probabilities of double-satellite and multiple-satellite coverage are all very high. These all provide the necessary system conditions for the cooperation communication through the satellite in the user downlink[6]. In the same way, a lot of user terminals also can cooperative communication with each other in the user uplink, such as terrestrial mobile cooperative communication. Thus, we present a generalized satellite mobile cooperative communication system model, which is shown in Fig. 2.

Fig. 2 shows that the proposed system consists of a source node(S), a relay node (C), and a destination node (D). The three nodes can communicate with each other. In order to prevent the relays from receiving and transmitting on interfering channels, which will cause coupling between their transmission and receive antennas, we allocate a different time slot so that transmissions of the source node and relay node are orthogonal.

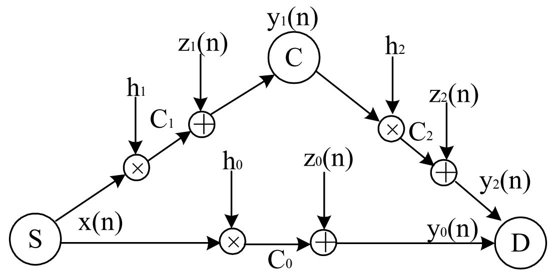

Fig.2. A satellite mobile cooperative communication system model

Our scheme has two phases. During the first phase, the source node broadcasts the information symbol $x(n)$ to the relay node and the destination node using channels C_0 and C_1 respectively, where n is the time index. The received signal at the destination and the relay from the source in the first phase can be written as:

(1) $$y_0(n) = h_0\sqrt{\varepsilon_0}x(n) + z_0(n)$$

(2) $$y_1(n) = h_1\sqrt{\varepsilon_0}x(n) + z_1(n)$$

Where ε_0 is the average total transmitted symbol energy of the source node.

In the second phase of transmission, we use a DF relaying scheme. The relay node fully decodes the source message by estimating the source codeword, and adopt CRC (Cyclic Redundancy Check) or not. Then, the relay node retransmits the signal $x_1(n)$ to the destination node. The received signal at the destination in the second phase becomes:

(3) $$y_2(n) = h_2\sqrt{\varepsilon_1}x_1(n) + z_2(n)$$

Where ε_1 is the average total transmitted symbol energy of the relay. The effect of the slowly varying flat fading is captured by h_0, h_1 and h_2, which we assume to be mutually independent and complex Gaussian distributed random variables with variance Ω_0, Ω_1 and Ω_2 respectively. We further assume that the additive noises $z_0(n)$, $z_1(n)$ and $z_2(n)$ are mutually independent complex-valued jointly Gaussian sequences with zero-mean and variances N_0, N_1 and N_2, respectively.

Considering the maximum ratio combining (MRC) of the received signals $y_0(n)$ and $y_2(n)$, we obtain the estimated information symbol at the destination can be written as:

(4) $$\begin{aligned}\hat{x}(n) &= \frac{h_0^*\sqrt{\varepsilon_0}}{N_0}y_0(n) + \frac{h_2^*\sqrt{\varepsilon_1}}{N_2}y_2(n)\\ &= \frac{|h_0|^2\varepsilon_0}{N_0}x(n) + \frac{|h_2|^2\varepsilon_1}{N_2}x_1(n) + \frac{h_0^*\sqrt{\varepsilon_0}}{N_0}z_0(n) + \frac{h_2^*\sqrt{\varepsilon_1}}{N_2}z_2(n)\end{aligned}$$

4 Performance analysis

In this section, we will derive the SER formula of the DF mode for BPSK modulation. If the relay node decodes the transmitted symbol correctly, the signal was transmitted by the relay $x_1(n) = x(n)$. If the relay node decodes the transmitted symbol incorrectly and without CRC(propagation error)，then $x_1(n) = -x(n)$,because of the BPSK modulation; while the relay node decodes the transmitted symbol incorrectly and take CRC, we can get $y_2(n) = 0$, because the relay node don't transmit signal. By substituting these expressions into (4), we can get the expressions for the average SNR.

4.1 The relay node decode correctly

The estimated information symbol at the destination can be rewritten by substituting $x_1(n) = x(n)$ into (4) as

(5) $$\hat{x}(n) = (\frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2})x(n) + \frac{h_0^*\sqrt{\varepsilon_0}}{N_0}z_0(n) + \frac{h_2^*\sqrt{\varepsilon_1}}{N_2}z_2(n)$$

We can write the instantaneous SNR in the destination as

(6) $$\gamma_d = \frac{(\frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2})^2}{\frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2}} = \frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2} = \gamma_0 + \gamma_2$$

Therefore, the average SNR in the destination is given by

(7) $$\bar{\gamma}_d = \bar{\gamma}_0 + \bar{\gamma}_2$$

4.2 The relay node decode incorrectly

4.2.1 Without CRC

Under case that without CRC, the estimated information symbol at the destination can be rewritten by substituting $x_1(n) = -x(n)$ into (4)

(8) $$\hat{x}(n) = (\frac{|h_0|^2\varepsilon_0}{N_0} - \frac{|h_2|^2\varepsilon_1}{N_2})x(n) + \frac{h_0^*\sqrt{\varepsilon_0}}{N_0}z_0(n) + \frac{h_2^*\sqrt{\varepsilon_1}}{N_2}z_2(n)$$

We can write the instantaneous SNR in the destination as:

(9) $$\gamma_d = \frac{(\frac{|h_0|^2\varepsilon_0}{N_0} - \frac{|h_2|^2\varepsilon_1}{N_2})^2}{\frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2}}$$

We assume that the variance of the source-destination and relay-destination channels to be equal, and that the relay and the destination have the same value of noise power. Furthermore, we assume equal power allocation in two senders, namely $\Omega_0 = \Omega_2$, $N_0 = N_2$, $\varepsilon_0 = \varepsilon_1$.

Therefore, the average SNR in the destination is given by

(10) $$\begin{aligned}\bar{\gamma}_d = E(\gamma_d) &= E(\frac{(\frac{|h_0|^2\varepsilon_0}{N_0} - \frac{|h_2|^2\varepsilon_1}{N_2})^2}{\frac{|h_0|^2\varepsilon_0}{N_0} + \frac{|h_2|^2\varepsilon_1}{N_2}})\\ &= \frac{(\frac{E(|h_0|^2)\varepsilon_0}{N_0} - \frac{E(|h_2|^2)\varepsilon_1}{N_2})^2}{\frac{E(|h_0|^2)\varepsilon_0}{N_0} + \frac{E(|h_2|^2)\varepsilon_1}{N_2}}\\ &= \frac{(\frac{\Omega_0\varepsilon_0}{N_0} - \frac{\Omega_2\varepsilon_1}{N_2})^2}{\frac{\Omega_0\varepsilon_0}{N_0} + \frac{\Omega_2\varepsilon_1}{N_2}} = 0\end{aligned}$$

4.2.2 With CRC

Under case that with CRC, we assume that when the source sends out information, an ideal cyclic redundancy check (CRC) code has been applied over the information symbols in the relay. The estimated information symbol at the destination can be rewritten as

(11) $$\hat{x}(n) = \frac{|h_0|^2 \varepsilon_0}{N_0} x(n) + \frac{h_0^* \sqrt{\varepsilon_0}}{N_0} z_0(n)$$

We can write the instantaneous SNR in the destination as

(12) $$\gamma_d = \gamma_0$$

The average SNR in the destination is given by

(13) $$\bar{\gamma}_d = \bar{\gamma}_0$$

Assumed that d is the error event of D, and c is the error event of C, the expression for the symbol error rate (SER) of D is given:

(14) $$P_d = P(d/c) \times P_c + P(d/\bar{c}) \times P_{\bar{c}}$$

where P_c is the probability of error at the relay and $P_c + P_{\bar{c}} = 1$. Let p is the bit error rate of the relay .If the relay node adopt CRC, then $P_c = 1-(1-p)^m$ (m as the frame length), or not $P_c = p$. Noting $P(d/\bar{c})$ as the probability of error from the relay to the destination given that the relay decoded successfully, and P_2 is the symbol error rate of two signals with MRC reception, according to equation (7), we can get $P(d/\bar{c}) = P_2$. $P(d/c)$ is the probability of error from the relay to the destination given that the relay decoded unsuccessfully, and P_1 is the symbol error rate of single signal. If the relay node adopt CRC, according to equation (12), we can get $P(d/c) = P_1$. Or not, $P(d/c) = \frac{1}{2}$ by using (10).

The symbol error rate (SER) at the destination when BPSK modulation is used can be written as

(15） $$P_d = \begin{cases} P_2 + (\frac{1}{2} - P_2) \times p & without\ CRC \\ P_1 + (P_2 - P_1) \times (1-p)^m & with\ \ CRC \end{cases}$$

If a satellite is cooperative with the other satellite , the channel fading from the satellite to the other satellite can be regarded as Gauss distributed .On the contrary , a user terminal also can cooperative with the other, the channel fading from the user terminal to the other can be regarded as Rayleigh distributed. Thus, if we decide that the framework, p can be calculated out immediately.

According to Eq. (8.22) of Ref.8, the BER for MRC can be expressed as

（16） $$P_b(E) = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \prod_{l=1}^{L} M_{\gamma_l}(-\frac{g}{\sin^2 \phi}) d\phi$$

Where $M_{\gamma}(s)$ is Moment Generating Function of the SNR per symbol γ_l associated with path L, g=1 for coherent BPSK. By substituting L=1 or L=2 into (10), P_1 and P_2 can be calculated respectively .We give out P_1 and P_2 over independent identically distributed satellite mobile channels (Rayleigh channels, Rician channels and shadowed Rician channels etc.) in appendix A, B and C.

Thus, we can get the SER performance of DF cooperative scheme over various satellite mobile channels by substituting p, P_1 and P_2 into (9).

5 Simulation results

In order to illustrate the above theoretical analysis, we performed some computer simulations using Matlab software in this section. In all simulations, we assumed that the variance of the noise is 1 (i.e., $N_0 = N_1 = N_2$ =1), and the variance of all the channels is 1 (i.e., $\Omega_0 = \Omega_1 = \Omega_2$ =1). We assume that the average total transmitted symbol energy of the DF relay cooperative system is E_s .With above assumption, we can get $\varepsilon_0 = \varepsilon_1 = \frac{1}{2} E_s$ .Thus, the average SNR per bit is $\bar{\gamma} = \frac{E_s}{2N_0}$. Three typical mobile satellite channels are selected to simulate, including Rayleigh channels, average shadowed Rician channels(σ_a^2 =0.252, m_u =-0.115, σ_u =0.161,[11]) and Rician channels($\kappa = 10(dB)$,where κ is the Rician factor of the Rician fading).

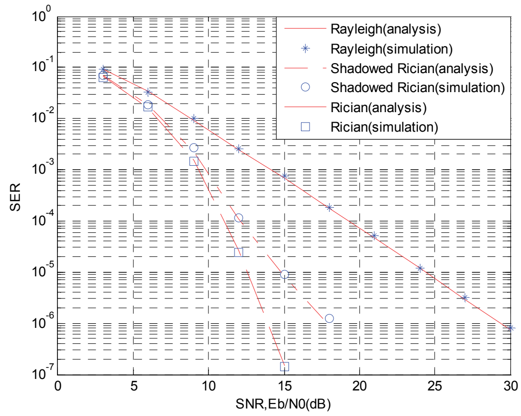

Fig.3. SER of C_1 is AWGN channel and without CRC

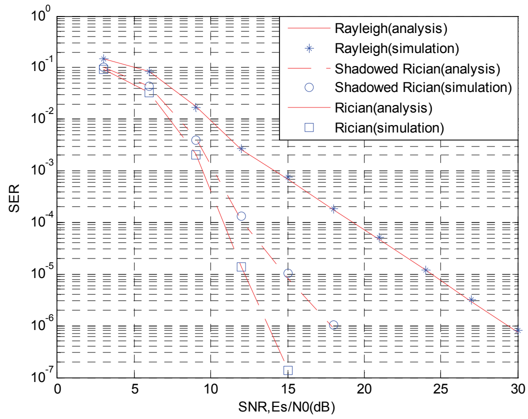

Fig.4. SER of C_1 is AWGN channel and with CRC

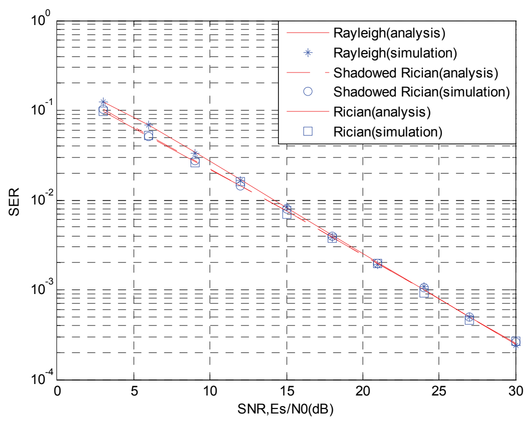

Fig.5. SER of C_1 is Rayleigh channel and without CRC

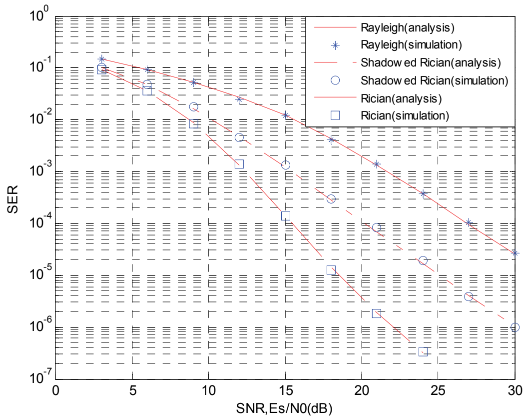

Fig.6. SER of C_1 is Rayleigh channel and with CRC

We simulated the DF relay cooperative systemat first, in which C_1 is AWGN channel and C_0 and C_2 are independent identically distributed satellite mobile channels (Rayleigh channels, shadowed Rician channels and Rician channels etc.). Thus , $p = Q(\sqrt{2\bar{\gamma}})$, P_1 and P_2 are calculated from the appendix A, B and C .By substituting these parameters into (9),we plotted the exact SER calculation as shown in Fig. 3 (without CRC in the relay node)and Fig. 4(with CRC in the relay node). From Fig. 3 and Fig. 4, we can see that the exact SER calculation fits to the simulation curve. Because C_1 is AWGN channel,the SER of source node to relay node is very low,especially when the SNR is high , the performance of the relay node with CRC have approximative SER curve with that without CRC.

We also simulated the DF relay cooperative system, in which C_1 is Rayleigh channel and C_0 and C_2 are independent identically distributed satellite mobile channels(Rayleigh channels, shadowed Rician channels and Rician channels etc.). Thus , $p = \frac{1}{2}(1 - \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}})$, P_1 and P_2 are calculated from the appendix A, B and C .By substituting these parameters into (9),we plotted the exact SER calculation as shown in Fig. 5 (without CRC in the relay node)and Fig. 6(with CRC in the relay node). From Fig.5 and Fig.6, we can see that the exact SER calculation fits to the simulation curve. Compare Fig.5 with Fig.6, we can see that the relay node take CRC outperforms the relay node without CRC with performance improvement over three typical satellite mobile channels.

6 Conclusion

In this paper, due to the complexity of satellite mobile propagation channel environment, we present a satellite mobile cooperative communication system model and derive two generalized error probability expressions with CRC or not. We also derive and simulate SER performance of the proposed system over various satellite mobile channels. The results show that the analytical results are in great accordance with the ones obtained by simulation. Also, it was shown that, whether adopt CRC or not depends on the channel link quality between the source node and the relay node.

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Appendices

Appendix A

In this appendix, we assumed that C_0 and C_2 are independent identically distributed Rayleigh channels. According to Tab. (2.2) of Ref.8, the MGF of Rayleigh fading is : $M_\gamma(s) = (1 - s\bar{\gamma})^{-1}$ .By substituting this MGF and L=1 or L=2 into (16), P_1 and P_2 is given by:

$$P_1 = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (1 + \frac{\bar{\gamma}}{\sin^2\phi})^{-1} d\phi = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} \frac{\sin^2\phi}{\sin^2\phi + \bar{\gamma}} d\phi$$

(17)

$$= \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (1 - \frac{\bar{\gamma}}{\sin^2\phi + \bar{\gamma}}) d\phi = \frac{1}{2} - \frac{\bar{\gamma}}{\pi}\int_0^{\frac{\pi}{2}} \frac{1}{\sin^2\phi + \bar{\gamma}} d\phi$$

$$P_2 = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (1 + \frac{\bar{\gamma}}{\sin^2\phi})^{-2} d\phi = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} (1 - \frac{\bar{\gamma}}{\sin^2\phi + \bar{\gamma}})^2 d\phi$$

(18)

$$= \frac{1}{2} - \frac{2\bar{\gamma}}{\pi}\int_0^{\frac{\pi}{2}} \frac{1}{\sin^2\phi + \bar{\gamma}} d\phi + \frac{\bar{\gamma}^2}{\pi}\int_0^{\frac{\pi}{2}} \frac{1}{(\sin^2\phi + \bar{\gamma})^2} d\phi$$

$$= \frac{1}{2} - \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}} + \frac{\bar{\gamma}^2}{\pi}\int_0^{\frac{\pi}{2}} \frac{1}{(\sin^2\phi + \bar{\gamma})^2} d\phi$$

where we use Eq. (2.562 and 2.563) of Ref.9, P_1 and P_2 can be written as

(19) $P_1=\frac{1}{2}\times(1-\sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}})$

(20) $P_2=\frac{1}{4}\times((\sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}})^3-3\sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}}+2)$

Appendix B

In this appendix, we assumed that C_0 and C_2 are independent identically distributed Rician channels.According to Tab. (2.2) of Ref.8 and $\kappa=n^2$, where κ is the Rician factor of the Rician fading.The MGF of Rician fading is

(21) $M_\gamma(s)=\frac{(1+\kappa)}{(1+\kappa-s\bar{\gamma})}\exp(\frac{\kappa s\bar{\gamma}}{1+\kappa-s\bar{\gamma}})$

By substituting this MGF and L=1 or L=2 into (16), P_1 and P_2 is given by:

(22) $P_1=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\frac{(1+\kappa)}{(1+\kappa+\frac{\bar{\gamma}}{\sin^2\phi})}\exp(\frac{-\kappa\frac{\bar{\gamma}}{\sin^2\phi}}{1+\kappa+\frac{\bar{\gamma}}{\sin^2\phi}})d\phi$

(23) $P_2=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left[\frac{(1+\kappa)}{(1+\kappa+\frac{\bar{\gamma}}{\sin^2\phi})}\right]^2\exp(\frac{-2\kappa\frac{\bar{\gamma}}{\sin^2\phi}}{1+\kappa+\frac{\bar{\gamma}}{\sin^2\phi}})d\phi$

Following the same steps from (5-20) to (5-22) as in [11], P_1 and P_2 can be rewritten as

(24)
$$P_1=\frac{e^{-\kappa}}{2\sqrt{\pi}}\sum_{t=0}^{\infty}\frac{\Gamma(t+3/2)\kappa^t}{\Gamma(t+2)t!\left(1+\frac{\bar{\gamma}}{1+\kappa}\right)^{1+t}}\times{}_2F_1\left(1+t,\frac{1}{2};t+2;\frac{1+\kappa}{1+\kappa+\bar{\gamma}}\right)$$

(25)
$$P_2=\frac{e^{-2\kappa}}{2\sqrt{\pi}}\sum_{t=0}^{\infty}\frac{\Gamma(t+5/2)(2\kappa)^t}{\Gamma(t+3)t!\left(1+\frac{\bar{\gamma}}{1+\kappa}\right)^{2+t}}\times{}_2F_1\left(t+2,\frac{1}{2};t+3;\frac{1+\kappa}{1+\kappa+\bar{\gamma}}\right)$$

Where ${}_2F_1(a,b;c;x)$ is Hypergeometric function

(26) ${}_2F_1(a,b;c;x)\overset{\Delta}{=}\sum_{n=0}^{\infty}\frac{(a)_n(b)_n}{(c)_n n!}x^n$

Where $(a)\overset{\Delta}{=}\Gamma(a+n)/\Gamma(a)$ is Pochhammer symbol。

Appendix C

In this appendix, we assumed that C_0 and C_2 are assumed as independent identically distributed shadowed Rician channels. According to Eq. (5-47) of Ref.11 and $n_T n_R=1$.The MGF of shadowed Rician fading is

(27) $M_\gamma(s)=\frac{\exp(-\Delta(s))}{\left(1+s\bar{\gamma}\sigma_a^2\right)}\left[1-2\sigma_\mu^2\Delta(s)+2\sigma_\mu^2(\Delta(s))^2\right]$

where $\Delta(s)=\frac{s\bar{\gamma}}{1+s\sigma_a^2\bar{\gamma}}\exp(2m_\mu)$ .The line-of-sight(LOS) signal component Z are modeled as mean with μ,complex Gaussian random variables with variances 0.5σ_a^2.Thus, Z～CN(μ , σ_a^2). μ is modeled as mean with m_u ,complex Gaussian random variables with variances σ_u .

By substituting this MGF and L=1 or L=2 into (16), P_1 and P_2 is given by:

(28) $P_1=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\frac{\exp\left(-\Delta\left(\frac{1}{\sin^2\theta}\right)\right)}{\left(1+\frac{\bar{\gamma}}{\sin^2\phi}\sigma_a^2\right)}\left[1-2\sigma_\mu^2\Delta\left(\frac{1}{\sin^2\theta}\right)+2\sigma_\mu^2\left(\Delta\left(\frac{1}{\sin^2\theta}\right)\right)^2\right]d\phi$

(29) $P_2=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\frac{\exp\left(-2\Delta\left(\frac{1}{\sin^2\theta}\right)\right)}{\left(1+\frac{\bar{\gamma}}{\sin^2\phi}\sigma_a^2\right)^2}\left[\left[1-2\sigma_\mu^2\Delta\left(\frac{1}{\sin^2\theta}\right)+2\sigma_\mu^2\left(\Delta\left(\frac{1}{\sin^2\theta}\right)\right)^2\right]\right]^2 d\phi$

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