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Enhancement of Multicast Security with Opportunistic Relaying Technique over *κ*-*μ* Shadowed Fading Channels

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Abstract

The effects of scatterers, fluctuation parameter and propagation clusters significantly affect the performance of κ-μ shadowed fading channel. On the other hand, opportunistic relaying is an efficient technique to improve the performance of fading channels reducing the effects of aforementioned parameters. Motivated by these issues, in this paper, a secure wireless multicasting scenario through κ-μ shadowed fading channel is considered in the presence of multiple eavesdroppers with opportunistic relaying. The main purpose of this paper is to ensure the security level in wireless multicasting compensating the loss of security due to the effects of power ratio between dominant and scattered waves, fluctuation parameter, and the number of propagation clusters, multicast users and eavesdroppers, by opportunistic relaying technique. The closed-form analytical expressions are derived for the probability of non-zero secrecy multicast capacity (PNSMC) and the secure outage probability for multicasting (SOPM) to understand the insight of the effects of above parameters. The results show that the loss of security in multicasting through κ-μ shadowed fading channel can be significantly enhanced using opportunistic relaying technique by compensating the effects of scatterers, fluctuation parameter, and the number of propagation clusters, multicast users and eavesdroppers.

Keywords

Opportunistic Relaying, Probability of Non-Zero Secrecy Multicast Capacity (PNSMC), Secure Wireless Multicasting, Secure Outage Probability for Multicasting (SOPM), κ-μ Shadowed Fading Channel

1. Introduction

The statistical characterization of fading is an important issue in wireless communication system. The most promising method, for improving wireless links by reducing the impacts of fading, scatterers, fluctuations, etc., is cooperative diversity with the best relay selection [1] [2] [3] [4]. On the other hand, multicasting is an effective means of group-oriented wireless data transmission such as video-conference, distance education [5], etc. The open nature of wireless network makes them vulnerable to fraud and eavesdropping. The conventional cryptographic schemes are not able to provide a secure framework for multicasting. Therefore, a key strategy for achieving information-theoretic security in multicasting is the physical layer security.

1.1. Related Works

Recently, zero-forcing (ZF) multiplexing system was used in [6] [7] to increase the spectral efficiency with the help of linear equalization. The secrecy performance of wireless physical layer security was analyzed in [8] over α-κ-μ and α-η-μ fading channels. The physical layer security was studied in [9] over κ-μ/Gamma composite fading channels. In [10], author focused on the performance comparison of multicasting over Rician-K and Rayleigh fading channels. In [11] [12], authors investigated the secrecy performance over the cascaded α-μ fading channels. In the above papers, they did not consider the effects of shadowing.

Wyner's wiretap model was used in [13] [14] to investigate the secrecy performance over κ-μ shadowed fading channels. In [15], author studied the performance of receiver by different types of diversity combining techniques. Authors analyzed the secrecy capacity in [16] considering the effects of interferences. The security in κ-μ shadowed fading channels was analyzed in [17] with the ergodic secrecy capacity. In [18], author showed the effects of scattering over multiple-input multiple-output (MIMO) system. In [19], author investigated the effects of shadowing on the performance of multicasting over κ-μ shadowed fading channels. In [20], authors investigated the effects of correlation and shadowing on the performance of multicasting. But the authors of the above papers did not consider the opportunistic relaying technique enhancing security for multicasting.

1.2. Contributions

Based on the aforementioned scenario available in the literature and motivated by the importance of security in multicasting, the authors in this work investigated a secure wireless multicasting scenario using κ-μ shadowed fading channels when multiple eavesdroppers are present. Authors developed a mathematical model to ensure that security in κ-μ shadowed fading channels with opportunistic relaying system. We can summarize the major contributions of this paper below.

- At first, based on the probability density function (PDF) of κ-μ shadowed fading channels [15], authors derived closed-form analytical expressions for the PNSMC and the SOPM.

- Then, the effects of power ratio between dominant and scattered waves, fluctuation parameter, and the number of propagation clusters, multicast users, eavesdroppers and relays on the PNSMC and the SOPM are investigated.
- Finally, the derived analytical expressions are justified via Monte-Carlo simulation.

The remaining part of this paper has been arranged as follows. Section II explains the system model and section III narrates the problem formulation. The equations for the PNSMC and the SOPM have been derived respectively in Section IV and V. Section VI describes the numerical results. In the end, the conclusions of this paper are represented in Section VII.

2. System Model

A secure wireless multicasting communication scenario shown in Figure 1 is considered through κ-μ Shadowed fading channels in the presence of multiple eavesdroppers. This figure consists of one transmitter, a group of R relays, M number of destination receivers and N number of eavesdroppers. The transmitter sends a common stream of confidential information to the M destination receivers via R relays. The eavesdroppers are trying to decode that confidential information. The objective of this research is to establish a secure communication between transmitter and destination receivers by preventing this eavesdropping. The channel between transmitter and destination receiver is known as multicast channel and the channel between transmitter and eavesdropper is known as eavesdropper's channel. We consider all the multicast channels and eavesdropper's

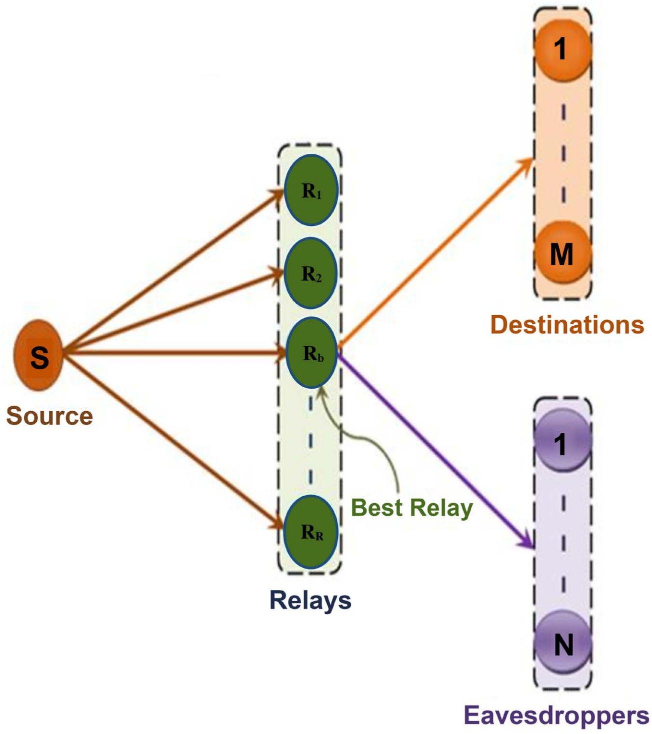

Figure 1. System model.

channels experience independent κ-μ shadowed fading. κ and μ denote two physical fading parameters of this system. κ reflects a real positive number representing the power ratio between dominant and scattered-wave components and μ reflects a positive real number representing the effective number of propagation clusters.

3. Problem Formulation

This section deals with the derivation of the closed-form analytical expressions for the PDFs of multicast channels and eavesdropper's channels.

3.1. The PDF of κ-μ Shadowed Fading Channels

Let γ denotes the SNR of each sub-channel of multicast channel. Then, the PDF of γ denoted by $f_\gamma(\gamma)$ for the κ-μ shadowed fading channels is given by [15] [17],

$$f_\gamma(\gamma)=\frac{\mu^\mu m^m(1+k)^\mu}{\Gamma(\mu)(m+\mu k)^m\bar{\gamma}}\left(\frac{\gamma}{\bar{\gamma}}\right)^{\mu-1}\mathrm{e}^{-\mu(1+k)\frac{\gamma}{\bar{\gamma}}}\,{}_1F_1\left(m,\mu;\frac{\mu^2k(1+k)}{\mu k+m}\frac{\gamma}{\bar{\gamma}}\right),\quad(1)$$

where ${}_1F_1(.,.;.)$ is the confluent hypergeometric function which is defined as ${}_1F_1(p,q;r)=\frac{\Gamma(q+1)}{\Gamma(p+1)}\sum_{n=0}^{\infty}\frac{\Gamma(p+n)}{\Gamma(q+n)}\frac{r^n}{n!}$. Substituting this formula in Equation (1), $f_\gamma(\gamma)$ can be found as

$$f_\gamma(\gamma)=\sum_{n=0}^{\infty}A_1A_4\gamma^{n+\mu-1}\mathrm{e}^{-A_2\gamma},\quad(2)$$

where $A_1=\frac{\mu^\mu m^m(1+k)^\mu}{\Gamma(\mu)(m+\mu k)^m\bar{\gamma}^\mu}$, $A_2=\frac{\mu(1+k)}{\bar{\gamma}}$, $A_3=\frac{\mu^2k(1+k)}{(\mu k+m)\bar{\gamma}}$ and $A_4=\frac{\Gamma(\mu+1)}{\Gamma(m+1)}\sum_{n=0}^{\infty}\frac{\Gamma(m+n)}{\Gamma(\mu+n)}\frac{A_3^n}{n!}$.

3.2. The PDF of SNR of Source-to-kth Relay

Let $\gamma_{s,k}$ denotes the SNR of source-to-kth relay. Then, the PDF of $\gamma_{s,k}$ denoted by $f_{\gamma_{s,k}}(\gamma_{s,k})$ for the κ-μ shadowed fading channels is given by,

$$f_{\gamma_{s,k}}(\gamma_{s,k})=\sum_{n=0}^{\infty}s_1s_4\gamma_{s,k}^{n+\mu-1}\mathrm{e}^{-s_2\gamma_{s,k}},\quad(3)$$

where $s_1=\frac{\mu^\mu m^m(1+k)^\mu}{\Gamma(\mu)(m+\mu k)^m\bar{\gamma}_s^\mu}$, $s_2=\frac{\mu(1+k)}{\bar{\gamma}_s}$, $s_3=\frac{\mu^2k(1+k)}{(\mu k+m)\bar{\gamma}_s}$ and $s_4=\frac{\Gamma(\mu+1)}{\Gamma(m+1)}\sum_{n=0}^{\infty}\frac{\Gamma(m+n)}{\Gamma(\mu+n)}\frac{s_3^n}{n!}$.

3.3. The PDF of the SNR of kth Relay-to-ith Destination Receiver

Let $\gamma_{k,i}$ denotes the SNR of kth relay-to-ith destination receiver. Then, the PDF of the SNR of $\gamma_{k,i}$ denoted by $f_{\gamma_{k,i}}(\gamma_{k,i})$ for the κ-μ shadowed fading channel is given by,

$$f_{\gamma_{k,i}}\left(\gamma_{k,i}\right)=\sum_{n=0}^{\infty}a_1a_4\gamma_{k,i}^{n+\mu-1}\mathrm{e}^{-a_2\gamma_{k,i}}, \tag{4}$$

where $a_1=\frac{\mu^{\mu}m^{m}\left(1+k\right)^{\mu}}{\Gamma\left(\mu\right)\left(m+\mu k\right)^{m}\overline{\gamma}_a^{\mu}}$, $a_2=\frac{\mu\left(1+k\right)}{\overline{\gamma}_a}$, $a_3=\frac{\mu^2k\left(1+k\right)}{\left(\mu k+m\right)\overline{\gamma}_a}$ and $a_4=\frac{\Gamma\left(\mu+1\right)}{\Gamma\left(m+1\right)}\sum_{n=0}^{\infty}\frac{\Gamma\left(m+n\right)}{\Gamma\left(\mu+n\right)}\frac{a_3^n}{n!}$.

3.4. The PDF of SNR of *k*th Relay-to-*j*th Eavesdropper

Let $\gamma_{k,j}$ denotes the SNR of *k*th relay-to-*j*th eavesdropper. Then, the PDF of the SNR of $\gamma_{k,j}$ denoted by $f_{\gamma_{k,j}}\left(\gamma_{k,j}\right)$ for *κ*-*μ* shadowed fading channels is given by,

$$f_{\gamma_{k,j}}\left(\gamma_{k,j}\right)=\sum_{n=0}^{\infty}b_1b_4\gamma_{k,j}^{n+\mu-1}\mathrm{e}^{-b_2\gamma_{k,j}}, \tag{5}$$

where $b_1=\frac{\mu^{\mu}m^{m}\left(1+k\right)^{\mu}}{\Gamma\left(\mu\right)\left(m+\mu k\right)^{m}\overline{\gamma}_b^{\mu}}$, $b_2=\frac{\mu\left(1+k\right)}{\overline{\gamma}_b}$, $b_3=\frac{\mu^2k\left(1+k\right)}{\left(\mu k+m\right)\overline{\gamma}_b}$ and $b_4=\frac{\Gamma\left(\mu+1\right)}{\Gamma\left(m+1\right)}\sum_{n=0}^{\infty}\frac{\Gamma\left(m+n\right)}{\Gamma\left(\mu+n\right)}\frac{b_3^n}{n!}$.

3.5. The CDF of SNR of Best Relay for Source-to-*i*th Destination Link

Let γ_i denotes the SNR of best relay for source-to-destination link. Then, the CDF of γ_i denoted by $F_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)$ for the *κ*-*μ* shadowed fading channels is given by,

$$F_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)=\left\{F_{\gamma_{eqk}}\left(\gamma_i\right)\right\}^R=\left\{1-Pr\left(\gamma_{s,k}>\gamma_i\right)Pr\left(\gamma_{k,i}>\gamma_i\right)\right\}^R, \tag{6}$$

where $Pr\left(\gamma_{s,k}>\gamma_i\right)\triangleq\int_{\gamma_i}^{\infty}f_{\gamma_{s,k}}\left(\gamma_{s,k}\right)\mathrm{d}\gamma_{s,k}$ and $Pr\left(\gamma_{k,i}>\gamma_i\right)\triangleq\int_{\gamma_i}^{\infty}f_{\gamma_{k,i}}\left(\gamma_{k,i}\right)\mathrm{d}\gamma_{k,i}$. Substituting the values of $f_{\gamma_{s,k}}\left(\gamma_{s,k}\right)$ and $f_{\gamma_{k,i}}\left(\gamma_{k,i}\right)$, and using the following identity of [21],

$$\int_u^{\infty}x^n\mathrm{e}^{-\mu x}\mathrm{d}x=\mathrm{e}^{-\mu u}\sum_{k=0}^{n}\left(\frac{n!u^k}{k!\mu^{n-k+1}}\right) \tag{7}$$

the value of $Pr\left(\gamma_{s,k}>\gamma_i\right)$ and $Pr\left(\gamma_{k,i}>\gamma_i\right)$ can be calculated in closed-form. Then, substituting the values of $Pr\left(\gamma_{s,k}>\gamma_i\right)$ and $Pr\left(\gamma_{k,i}>\gamma_i\right)$ in Equation (6) and using the following identities of [21],

$$\left\{\sum_{k=0}^{\infty}\left(a_kx^k\right)\right\}^n=\sum_{k=0}^{\infty}\left(c_kx^k\right) \tag{8}$$

$$\left(a+x\right)^n=\sum_{i=0}^{n}\binom{n}{i}x^ia^{n-i}, \tag{9}$$

where $c_m=\frac{1}{ma_0}\sum_{k=1}^{m}\left(kn-m+k\right)a_kc_{m-k}$ for $m\geq1$ and $c_0=a_0^n$ for $m=0$

and n is an integer number, the closed-form expression for the $F_{\gamma_{\Sigma_{d_i}}}(\gamma_i)$ can be derived as

$$F_{\gamma_{\Sigma_{d_i}}}(\gamma_i)=\sum_{k_1=0}^{\infty}\sum_{k_2=0}^{R}\omega_4\gamma_i^{2k_1}\mathrm{e}^{-\omega_5 k_2\gamma_i}, \tag{10}$$

where $\omega_4=\sum_{k_2=0}^{R}\frac{R!(-1)^{k_2}}{R!(R-k_2)!}\left[\sum_{n=0}^{\infty}\frac{\omega_1(n+\mu-1)!}{q^{n+\mu}}\right]^{2k_2}$, $\omega_5=\frac{q}{\bar{\gamma}_s}+\frac{q}{\bar{\gamma}_m}$ and $q=\mu(1+k)$.

3.6. The CDF of SNR of Best Relay for Source-to-*j*th Eavesdropper Link

Let γ_j denotes the SNR of best relay for source-to-eavesdropper link. Then, the CDF of γ_j denoted by $F_{\gamma_{\Sigma_{e_j}}}(\gamma_j)$, for κ-μ shadowed fading channels is given by,

$$F_{\gamma_{\Sigma_{e_j}}}(\gamma_j)=\left\{F_{\gamma_{qk}}(\gamma_j)\right\}^R=\left\{1-Pr(\gamma_{s,k}>\gamma_i)Pr(\gamma_{k,j}>\gamma_j)\right\}^R, \tag{11}$$

where $Pr(\gamma_{s,k}>\gamma_j)\triangleq\int_{\gamma_j}^{\infty}f_{\gamma_{s,k}}(\gamma_{s,k})\mathrm{d}\gamma_{s,k}$ and $Pr(\gamma_{k,j}>\gamma_j)\triangleq\int_{\gamma_j}^{\infty}f_{\gamma_{k,j}}(\gamma_{k,j})\mathrm{d}\gamma_{k,j}$. Substituting the values of $f_{\gamma_{s,k}}(\gamma_{s,k})$ and $f_{\gamma_{k,j}}(\gamma_{k,j})$, and using the identities of Equations (7)-(9), the closed-form expression for the $F_{\gamma_{\Sigma_{e_j}}}(\gamma_j)$ can be defined as

$$F_{\gamma_{\Sigma_{e_j}}}(\gamma_j)=\sum_{k_1=0}^{\infty}\sum_{k_2=0}^{R}\beta_3\gamma_j^{2k_1}\mathrm{e}^{-\beta_2 k_2\gamma_j}, \tag{12}$$

where $\beta_2=\frac{q}{\bar{\gamma}_s}+\frac{q}{\bar{\gamma}_e}$, $q=\mu(1+k)$ and

$$\beta_3=\sum_{k_2=0}^{R}\frac{R!}{k_2!(R-k_2)!}(-1)^{k_2}\left[\sum_{n=0}^{\infty}\frac{\omega_1(n+\mu-1)!}{q^{n+\mu}}\right]^{2k_2}.$$

3.7. The PDF of SNR of Best Relay for Source-to-*i*th Destination Link

The PDF of γ_i denoted by $f_{\gamma_{\Sigma_{d_i}}}(\gamma_i)$ for κ-μ shadowed fading channel can be obtained as

$$f_{\gamma_{\Sigma_{d_i}}}(\gamma_i)=Rf_{\gamma_{eqk}}(\gamma_i)\left[F_{\gamma_{eqk}}(\gamma_i)\right]^{R-1}, \tag{13}$$

where the value of $f_{\gamma_{eqk}}(\gamma_i)$ can be calculated from the following expression

$$f_{\gamma_{eqk}}(\gamma_i)=\frac{\mathrm{d}}{\mathrm{d}\gamma_i}\left\{F_{\gamma_{eqk}}(\gamma_i)\right\}. \tag{14}$$

Substituting the value of $F_{\gamma_{eqk}}(\gamma_i)$ in Equation (14) and after differentiation, the closed-form expression of $f_{\gamma_{eqk}}(\gamma_i)$ is given by,

$$f_{\gamma_{eqk}}\left(\gamma_i\right)=\left(-2k_1\gamma_i^{2k_1-1}+\omega_5\gamma_i^{2k_1}\right)\omega_3\mathrm{e}^{-\omega_5\gamma_i}, \tag{15}$$

where $\omega_3=\sum_{k_1=0}^{\infty}\frac{\omega_2^2}{\left(\bar{\gamma}_s\bar{\gamma}_m\right)^{k_1}}$ and $\omega_5=\frac{q}{\bar{\gamma}_s}+\frac{q}{\bar{\gamma}_m}$. Finally, substituting the values of $f_{\gamma_{eqk}}\left(\gamma_i\right)$ and $F_{\gamma_{eqk}}\left(\gamma_i\right)$ in Equation (13) we have

$$f_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)=\left(\omega_7\gamma_i^{v_1}+\omega_8\gamma_i^{v_2}\right)\mathrm{e}^{-\omega_9\gamma_i}, \tag{16}$$

where $\omega_7=\sum_{k_1=0}^{\infty}-2\omega_3\omega_6k_1R$, $\omega_8=\omega_3\omega_5\omega_6R$, $\omega_9=\sum_{k_3=0}^{R-1}\omega_5\left(1+k_3\right)$, $v_1=v_2-1$ and $v_2=4\sum_{k_1=0}^{\infty}k_1$.

3.8. The PDF of SNR of Best Relay for Source-to-*j*th Eavesdropper Link

The PDF of γ_j denoted by $f_{\gamma_{\Sigma e_j}}\left(\gamma_j\right)$ for κ-μ shadowed fading channel can be defined as

$$f_{\gamma_{\Sigma e_j}}\left(\gamma_j\right)=Rf_{\gamma_{qk}}\left(\gamma_j\right)\left[F_{\gamma_{qk}}\left(\gamma_j\right)\right]^{R-1}. \tag{17}$$

The value of $f_{\gamma_{qk}}\left(\gamma_j\right)$ is calculated as follows,

$$f_{\gamma_{qk}}\left(\gamma_j\right)=\frac{\mathrm{d}}{\mathrm{d}\gamma_j}\left\{F_{\gamma_{qk}}\left(\gamma_j\right)\right\}=\left(-2k_1\gamma_j^{2k_1-1}+\beta_2\gamma_j^{2k_1}\right)\beta_1\mathrm{e}^{-\beta_2\gamma_j}, \tag{18}$$

where $\beta_1=\sum_{k_1=0}^{\infty}\frac{\omega_2^2}{\left(\bar{\gamma}_s\bar{\gamma}_e\right)^{k_1}}$ and $\beta_2=\frac{q}{\bar{\gamma}_s}+\frac{q}{\bar{\gamma}_e}$. Substituting the values of $f_{\gamma_{qk}}\left(\gamma_j\right)$ and $F_{\gamma_{qk}}\left(\gamma_j\right)$ in Equation (17), the closed-form expression for the $f_{\gamma_{\Sigma e_j}}\left(\gamma_j\right)$ can be derived as,

$$f_{\gamma_{\Sigma e_j}}\left(\gamma_j\right)=\left(\beta_5\gamma_j^{v_1}+\beta_6\gamma_j^{v_2}\right)\mathrm{e}^{-\beta_7\gamma_j}, \tag{19}$$

where $\beta_5=\sum_{k_1=0}^{\infty}-2k_1\beta_1\beta_4$, $\beta_6=\beta_1\beta_2\beta_4$, $\beta_7=\sum_{k_3=0}^{R-1}\beta_2\left(1+k_3\right)$, $v_1=v_2-1$ and $v_2=4\sum_{k_1=0}^{\infty}k_1$.

3.9. The PDF of $d_{\min}$

Let $d_{\min}=\min_{1\le i\le M}\gamma_i$ denotes the SNR of multicast channel. Then, the PDF of $d_{\min}$ denoted by $f_{d_{min}}(\gamma_i)$, for the κ-μ shadowed fading channel is given by,

$$f_{d_{\min}}\left(\gamma_i\right)=Mf_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)\left\{1-F_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)\right\}^{M-1}. \tag{20}$$

Substituting the value of $f_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)$ and $F_{\gamma_{\Sigma d_i}}\left(\gamma_i\right)$ in Equation (20), the closed-form analytical expression for the $f_{d_{\min}}\left(\gamma_i\right)$ can be derived as

$$f_{d_{\min}}\left(\gamma_i\right)=\left(\eta_3\gamma_i^{k_6}+\eta_4\gamma_i^{k_7}\right)\mathrm{e}^{-\eta_5\gamma_i}, \tag{21}$$

where

$$\eta_3 = \sum_{k_4=0}^{M-1} M \frac{(M-1)!}{k_4!((M-1)-k_4)!} (\omega_4)^{k_4} \omega_7,$$

$$\eta_4 = \sum_{k_4=0}^{M-1} M \frac{(M-1)!}{k_4!((M-1)-k_4)!} (\omega_4)^{k_4} \omega_8,$$

$$\eta_5 = \sum_{k_2=0}^{R} \sum_{k_4=0}^{M-1} (\omega_9 + \omega_5 k_2 k_4),$$

$$k_6 = \sum_{k_1=0}^{\infty} \sum_{k_4=0}^{M-1} (v_1 + 2k_1 k_4) \text{ and}$$

$$k_7 = \sum_{k_1=0}^{\infty} \sum_{k_4=0}^{M-1} (v_2 + 2k_1 k_4).$$

3.10. The PDF of $d_{\max}$

Let $d_{\max} = \max_{1 \le j \le N} \gamma_j$ denotes the maximum SNR of eavesdropper's channel. Then, the PDF of $d_{\max}$ denoted by $f_{d_{\max}}(\gamma_j)$, for the κ-μ shadowed fading channel is given by,

$$f_{d_{\max}}(\gamma_j) = N f_{\gamma_{\Sigma e_j}}(\gamma_j) \left\{ F_{\gamma_{\Sigma e_j}}(\gamma_j) \right\}^{N-1}. \tag{22}$$

Substituting the values of $f_{\gamma_{\Sigma e_j}}(\gamma_j)$ and $F_{\gamma_{\Sigma e_j}}(\gamma_j)$ in Equation (22), the closed- form analytical expression for the $f_{d_{\max}}(\gamma_j)$ can be derived as

$$f_{d_{\max}}(\gamma_j) = \frac{\eta_1 \gamma_j^{v_1+k_5} + \eta_2 \gamma_j^{v_2+k_5}}{e^{\beta_8 \gamma_j}}, \tag{23}$$

where $\beta_8 = \sum_{k_2=0}^{R} \{\beta_7 + \beta_2 k_2 (N-1)\}$, $\eta_1 = N \beta_3^{N-1} \beta_5$ and $\eta_2 = N \beta_3^{N-1} \beta_6$.

4. Probability of Non-Zero Secrecy Multicast Capacity

The PNSMC is defined as

$$Pr(C_{smcast} > 0) = \int_0^{\infty} f_{d_{\min}}(\gamma_i) \int_0^{\gamma_i} f_{d_{\max}}(\gamma_j) \mathrm{d}\gamma_j \mathrm{d}\gamma_i. \tag{24}$$

Substituting the values of $f_{d_{\min}}(\gamma_i)$ and $f_{d_{\max}}(\gamma_j)$ in Equation (24) and using the following identities of [21],

$$\int_0^u x^n e^{-\mu x} \mathrm{d}x = \frac{n!}{\mu^{n+1}} - e^{-\mu u} \sum_{k=0}^{n} \left(\frac{n! u^k}{k! \mu^{n-k+1}} \right) \tag{25}$$

$$\int_0^{\infty} x^n e^{-\mu x} \mathrm{d}x = n! \mu^{-n-1} \tag{26}$$

the derived analytical expression in the closed-form for the $Pr(C_{smcast} > 0)$ is shown in Equation (27) at the top of the next page, where

$\delta_1 = \frac{\eta_1 (v_1 + k_5)!}{\beta_8^{v_1+k_5+1}} + \frac{\eta_2 (v_2 + k_5)!}{\beta_8^{v_2+k_5+1}}$, $\delta_2 = (-1) \sum_{k_9=0}^{v_1+k_5} \frac{(v_1 + k_5)!}{k_9!} \frac{\eta_1}{\beta_8^{v_1-k_9+1}}$ and $\delta_3 = (-1) \sum_{k_8=0}^{v_2+k_5} \frac{(v_2 + k_5)!}{k_8!} \frac{\eta_2}{\beta_8^{v_2-k_8+1}}$.

$$\begin{aligned} &Pr\left(C_{smcast}>0\right) \\ &=\frac{\delta_1 k_6!}{\eta_5^{k_7}}\left\{\eta_3+\frac{\eta_4 k_7}{\eta_5}\right\}+\sum_{k_9=0}^{v_1+k_5}\frac{\delta_2\left(k_6+k_9\right)!}{\left(\beta_8+\eta_5\right)^{k_7+k_9}}\left\{\eta_3+\frac{\eta_4\left(k_7+k_9\right)}{\beta_8+\eta_5}\right\} \\ &+\sum_{k_8=0}^{v_2+k_5}\frac{\delta_3\left(k_6+k_8\right)!}{\left(\beta_8+\eta_5\right)^{k_7+k_8}}\left\{\eta_3+\frac{\eta_4\left(k_7+k_8\right)}{\beta_8+\eta_5}\right\} \end{aligned} \tag{27}$$

5. Secure Outage Probability for Multicasting

The SOPM is defined as

$$P_{out}\left(R_{smcast}\right)=1-\int_0^\infty f_{d_{\max}}\left(\gamma_j\right)\int_x^\infty f_{d_{\min}}\left(\gamma_i\right)\mathrm{d}\gamma_i\mathrm{d}\gamma_j, \tag{28}$$

where $x=\mathrm{e}^{2R_{smcast}}\left(1+\gamma_j\right)-1$, $x=H+\mathrm{e}^{2R_{smcast}}\gamma_j$, $H=\mathrm{e}^{2R_{smcast}}-1$ and R_{smcast} denotes the target secrecy multicast rate which is indicated as R_S in the figure.

Substituting the values of $f_{d_{\min}}\left(\gamma_i\right)$ and $f_{d_{\max}}\left(\gamma_j\right)$ in Equation (28) and using the identities of Equations (25) and (26), the derived analytical expression in the closed-form for the $P_{out}\left(R_{smcast}\right)$ is shown below in Equation (29) as

$$\begin{aligned} &P_{out}\left(R_{smcast}\right) \\ &=1-\left[\sum_{k_{11}=0}^{k_6}\sum_{k_{13}=0}^{k_{11}}\left\{\frac{\eta_1\eta_6\left(v_1+k_5+k_{13}\right)!}{\left(\beta_8+\eta_8\right)^{v_1+k_5+k_{13}+1}}\right\}+\sum_{k_{11}=0}^{k_6}\sum_{k_{13}=0}^{k_{11}}\left\{\frac{\eta_2\eta_6\left(v_2+k_5+k_{13}\right)!}{\left(\beta_8+\eta_8\right)^{v_2+k_5+k_{13}+1}}\right\}\right. \\ &\left.+\sum_{k_{12}=0}^{k_7}\sum_{k_{14}=0}^{k_{12}}\left\{\frac{\eta_1\eta_7\left(v_1+k_5+k_{14}\right)!}{\left(\beta_8+\eta_8\right)^{v_1+k_5+k_{14}+1}}\right\}+\sum_{k_{12}=0}^{k_7}\sum_{k_{14}=0}^{k_{12}}\left\{\frac{\eta_2\eta_7\left(v_2+k_5+k_{14}\right)!}{\left(\beta_8+\eta_8\right)^{v_2+k_5+k_{14}+1}}\right\}\right], \end{aligned} \tag{29}$$

where, $\eta_6=\sum_{k_{11}=0}^{k_6}\sum_{k_{13}=0}^{k_{11}}\frac{\eta_3\left(H\right)^{k_{11}-k_{13}}}{\left(\mathrm{e}^{\eta_5 H}\right)\left(\mathrm{e}^{-2R_s}\right)^{k_{13}}}\frac{k_6!}{k_{11}!}\frac{\frac{k_{11}!}{k_{13}!(k_{11}-k_{13})!}}{\eta_5^{k_6-k_{11}+1}}$,

$\eta_7=\sum_{k_{12}=0}^{k_7}\sum_{k_{14}=0}^{k_{12}}\frac{\eta_4\left(H\right)^{k_{12}-k_{14}}}{\left(\mathrm{e}^{\eta_5 H}\right)\left(\mathrm{e}^{-2R_s}\right)^{k_{14}}}\frac{k_7!}{k_{12}!}\frac{\frac{k_{12}!}{k_{14}!(k_{12}-k_{14})!}}{\eta_5^{k_7-k_{12}+1}}$ and $\eta_8=\eta_5\mathrm{e}^{2R_s}$.

6. Numerical Results

The PNSMC represented by $Pr\left(C_{smcast}>0\right)$ is depicted in **Figure 2** as a function of the multicast channel's average SNR (γ_s), for various values of κ and μ. This figure shows the impacts of κ and μ on the $Pr\left(C_{smcast}>0\right)$ for the given values of system parameters. We see that the $Pr\left(C_{smcast}>0\right)$ increases, if κ decrease from 2 (represented by the dot line) to 1 (represented by the solid line) when $\mu=1$. Again the $Pr\left(C_{smcast}>0\right)$ decreases, if μ increase from 1 (represented by the short dash line) to 1.4 (represented by the dash dot line) when $\kappa=2$.

The $Pr\left(C_{smcast}>0\right)$ is depicted in **Figure 3** as a function of the multicast channel's average SNR (γ_s), for various values of M and N. This figure shows the impacts of M and N on the $Pr\left(C_{smcast}>0\right)$ for the selected values of system parameters. It is found that the $Pr\left(C_{smcast}>0\right)$ increases, if N decrease from 2

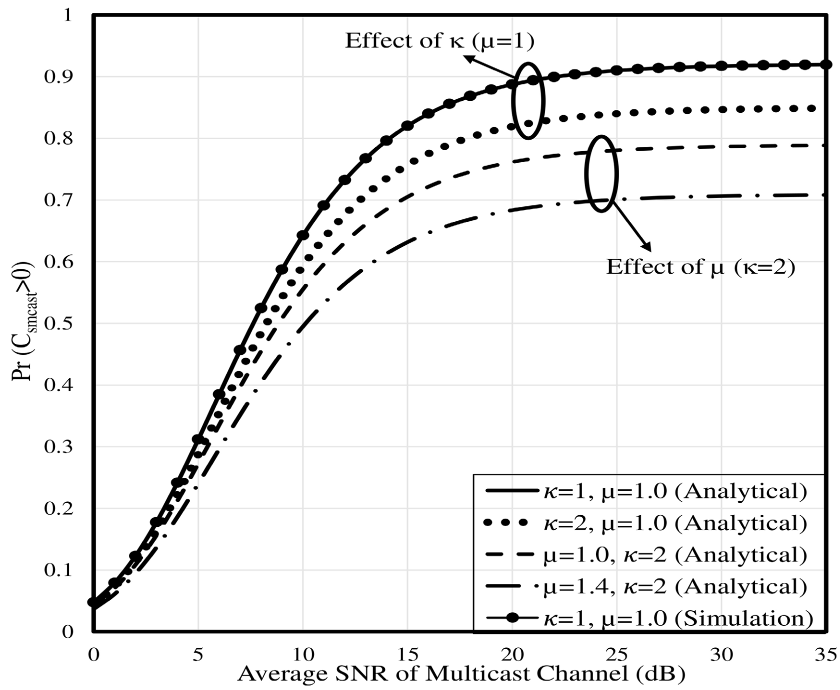

Figure 2. The effects of the power ratio between dominant and scattered-wave components, κ, and the effective number of propagation clusters, μ, on the $Pr\left(C_{smcast} > 0\right)$ for $N = 1$, $M = 1$, $m = 2.6$, $R = 1$ and $\gamma = -1.1\,\text{dB}$.

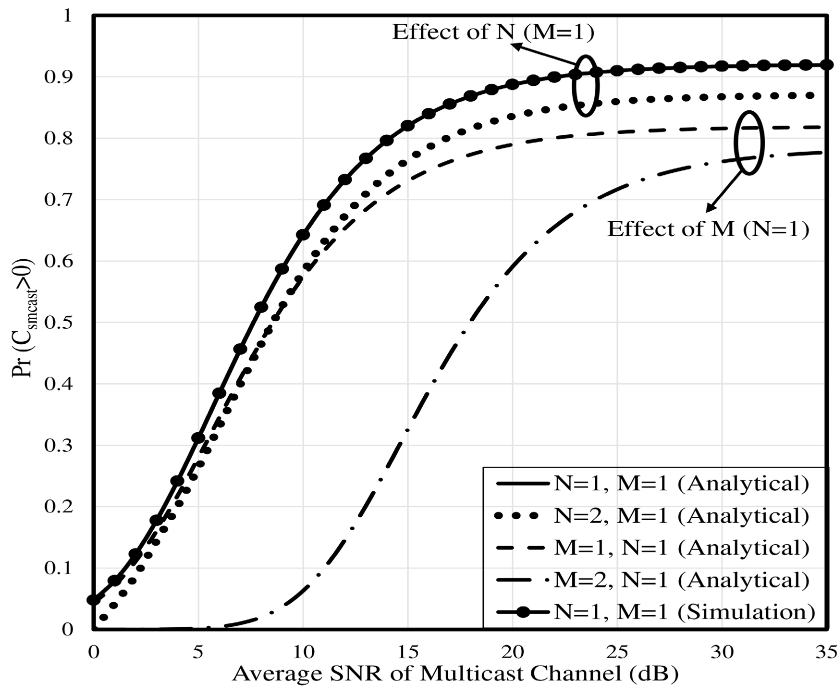

Figure 3. The effects of the number of multicast user, M, and the number of eavesdropper, N, on the $Pr\left(C_{smcast} > 0\right)$ for $\kappa = 2$, $\mu = 1$, $m = 2.6$, $R = 1$ and $\gamma = -1.5\,\text{dB}$.

(dot line) to 1 (solid line) and M decrease from 2 (dash dot line) to 1 (short dash line) when $M = 1$ and $N = 1$, respectively. This is due to the fact that when the number of multicast users increases, each user's bandwidth decreases, which in turn lowers the multicast user's capacity.

The $Pr\left(C_{smcast} > 0\right)$ is depicted in **Figure 4** as a function of the multicast channel's average SNR (γ_s), for various values of the number of relay, *R*, and fluctuation parameter, *m*. This figure shows the impacts of *R* and *m* on the $Pr\left(C_{smcast} > 0\right)$ for selected values of system parameters. We see that the $Pr\left(C_{smcast} > 0\right)$ increases, if *R* increase from 1 (dot line) to 2 (solid line) when $m = 2.5$. The $Pr\left(C_{smcast} > 0\right)$ also increases when the values of *m* decrease from 2.5 (dash dot line) to 1.5 (short dash line) when $R = 1$. This is because, increasing in the number of relay increases the diversity gain provided by the relays, and decreasing in the LOS fluctuation parameter decreases the severity of fading in the multicast channels which causes an improvement in the capacity of multicast user.

In **Figure 5**, the SOPM represented by $P_{out}\left(R_{smcast}\right)$ is illustrated as a function of the multicast channel's average SNR γ_s for various values of κ and *R*. For the selected values of system parameters, this figure illustrates how κ and *R* affect the SOPM, $P_{out}\left(R_{smcast}\right)$. We see that the $P_{out}\left(R_{smcast}\right)$ increases, if the values of κ increase from 1 to 1.6 and decreases if the values of *R* increase from 1 to 2 when $R = 1$ and $\kappa = 1.6$, respectively.

The impact of μ illustrates with *R* that is described in **Figure 6** by plotting the $P_{out}\left(R_{smcast}\right)$ against γ_s of the multicast channel. For the selected values of system parameters, this figure illustrates how μ and *R* affect the $P_{out}\left(R_{smcast}\right)$. We see that the $P_{out}\left(R_{smcast}\right)$ increases, if the values of μ increase from 1.2 to 1.5

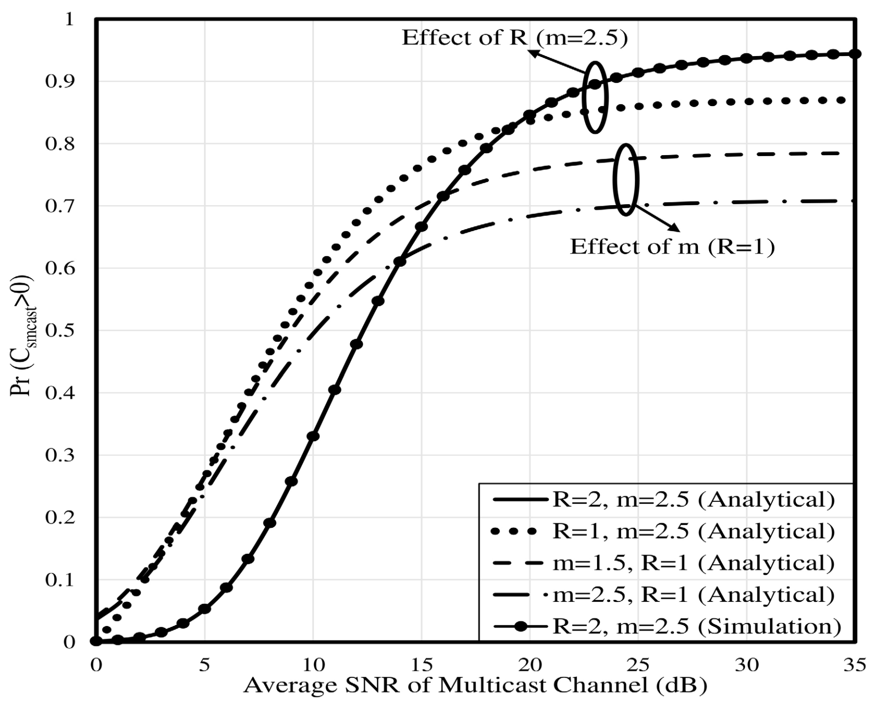

Figure 4. The effects of the number of relays *R* and fluctuation parameter, *m*, on the $Pr\left(C_{smcast} > 0\right)$ for $M = 1$, $N = 1$, $\kappa = 3$, $\mu = 1$ and $\gamma = 2\,\text{dB}$.

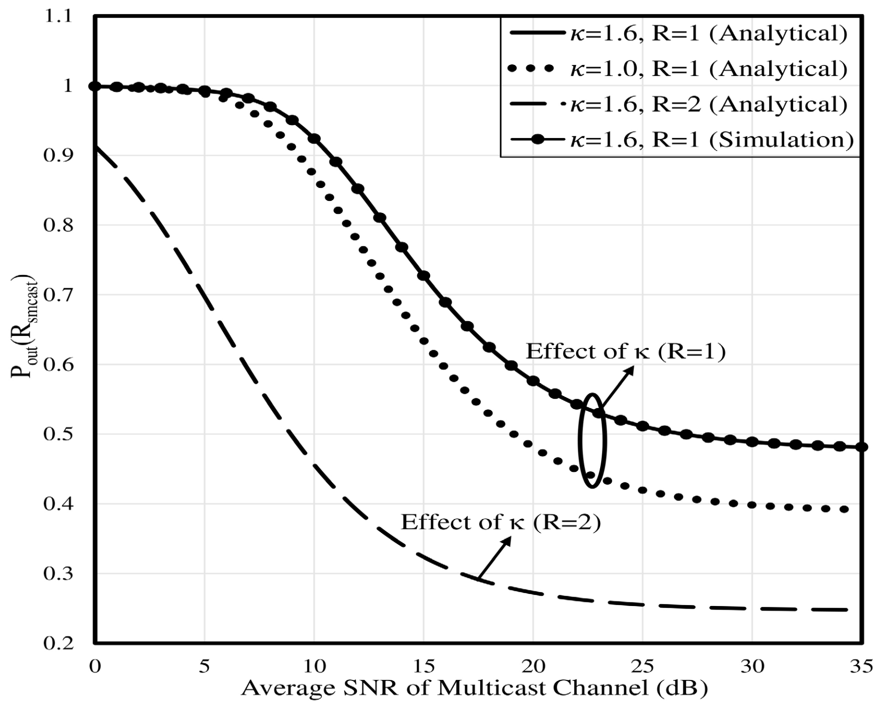

Figure 5. The effects of κ and R on the $P_{out}\left(R_{smcast}\right)$ for $N=1$, $M=1$, $\mu=1$, $m=1$, $R_s=0.8$ and $\gamma=2\text{ dB}$.

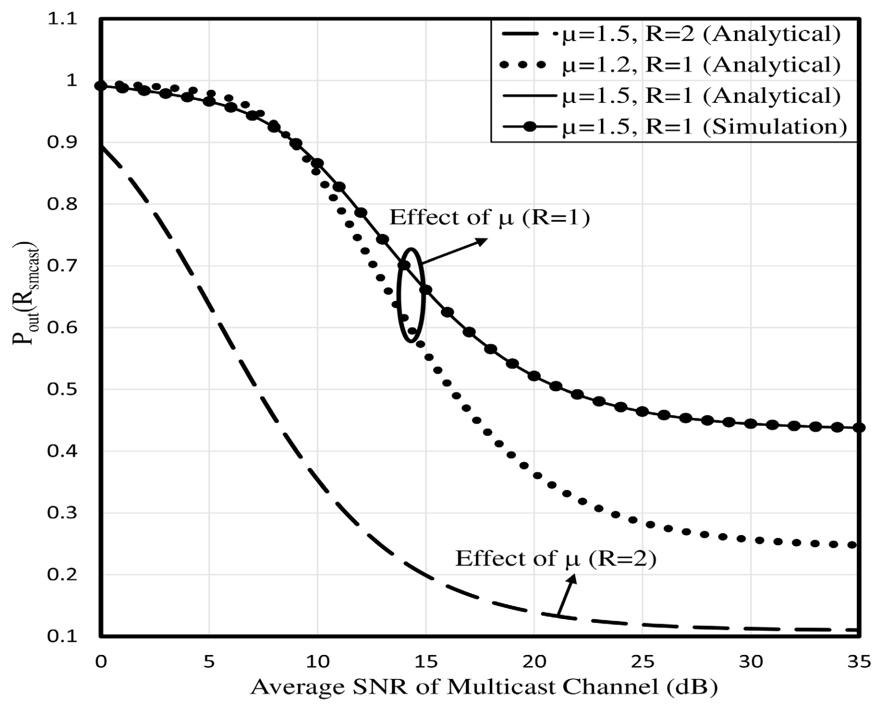

Figure 6. The effects of μ and R on the $P_{out}\left(R_{smcast}\right)$ for $N=1$, $M=1$, $\kappa=1$, $m=0.7$, $R_s=0.9$ and $\gamma=1\text{ dB}$.

and decreases if the value of R increase from 1 to 2 when $R=1$ and $\mu=1.5$, respectively.

In **Figure 7**, the $P_{out}(R_{smcast})$ is illustrated as a function of the multicast channel's average SNR γ_s for various values of M and R. For the given values of system parameters, this figure illustrates how M and R affect the $P_{out}(R_{smcast})$. We see that the $P_{out}(R_{smcast})$ increases, if M increase from 1 to 2 when $R=1$. The $P_{out}(R_{smcast})$ decreases if the value of R increase from 1 (represented by at the very top) to 2 (represented by lowest) when $M=2$ in the high SNR region, as one expects.

In **Figure 8**, the $P_{out}(R_{smcast})$ is illustrated as a function of the multicast channel's average SNR γ_s for various values of N and R. For the given values of system parameters, this figure narrates how N and R affect the SOPM, $P_{out}(R_{smcast})$. It is observed that the $P_{out}(R_{smcast})$ increases, if N increase from 1 (dot line) to 2 (solid line) when $R=1$. The $P_{out}(R_{smcast})$ decreases with R.

The $P_{out}(R_{smcast})$ is plotted against γ_s which shows in **Figure 9** of the multicast channel for various values of m and R. This figure shows the impacts of m and R on the $P_{out}(R_{smcast})$ for the given system parameters. We see that the $P_{out}(R_{smcast})$ increases, if m increase from 1 to 2 when $R=1$. This effect of m increases when the value of R increases.

The $P_{out}(R_{smcast})$ is depicted in **Figure 10** as a function of the multicast channel's average SNR (γ_s), for the values of $R=1$ and $R=2$. This figure shows the impacts of R on the $P_{out}(R_{smcast})$ for the given system parameters. We see that the $P_{out}(R_{smcast})$ increases if the values of R decrease from 2 to 1 when $M=N=1$. The cooperative diversity provided by the best relay increases with the number of relays which is a reason of an improvement in the multicast capacity.

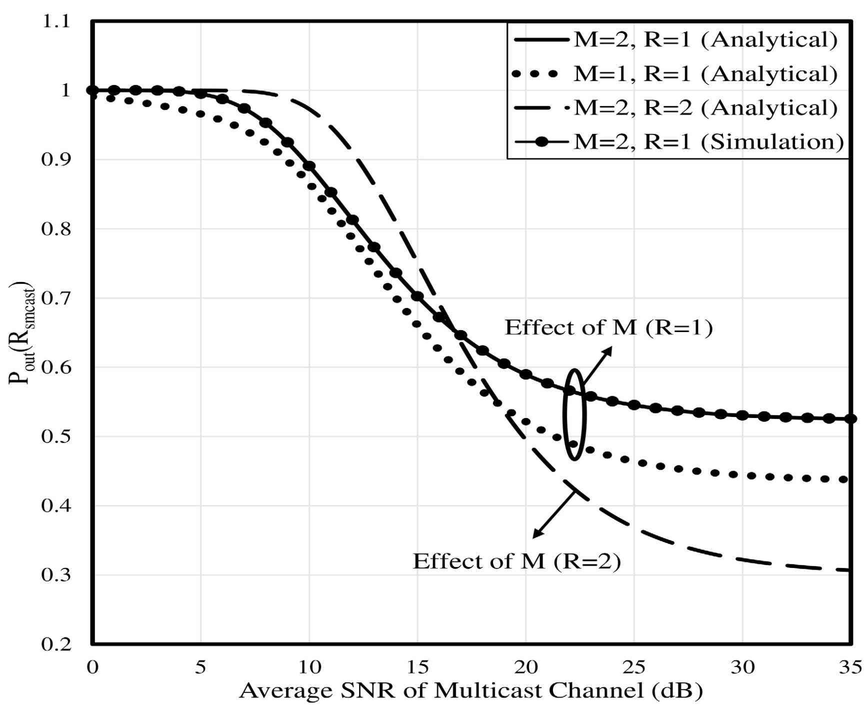

Figure 7. The effects of M and R on the $P_{out}(R_{smcast})$ for $N=1$, $\mu=1$, $\kappa=1$, $m=0.7$, $R_s=0.8$ and $\gamma=-5$ dB.

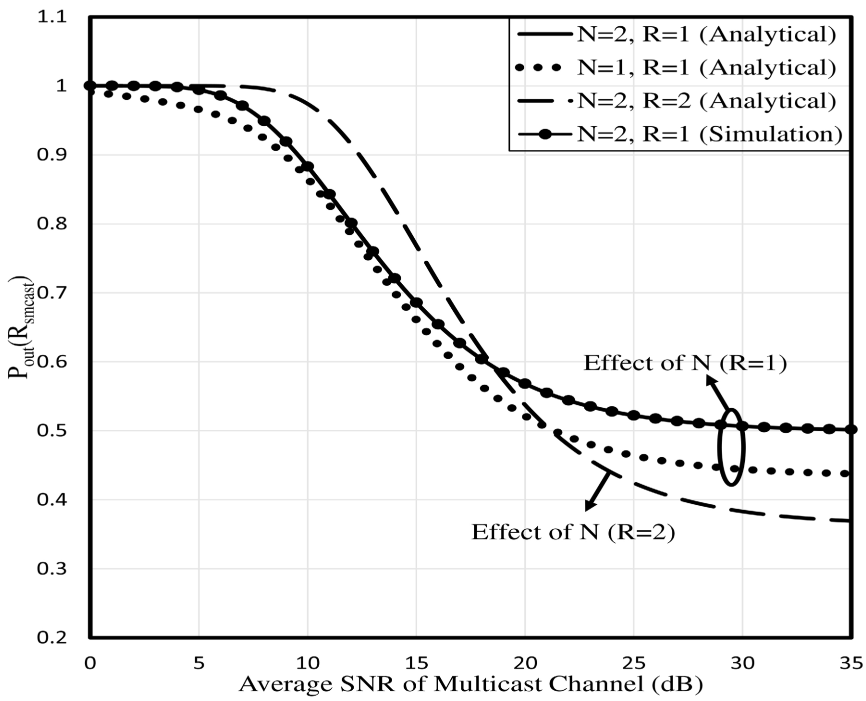

Figure 8. The effects of N and R on the $P_{out}\left(R_{smcast}\right)$ for $M=1$, $\mu=1$, $\kappa=1$, $m=0.5$, $R_s=0.9$ and $\gamma=-5$ dB.

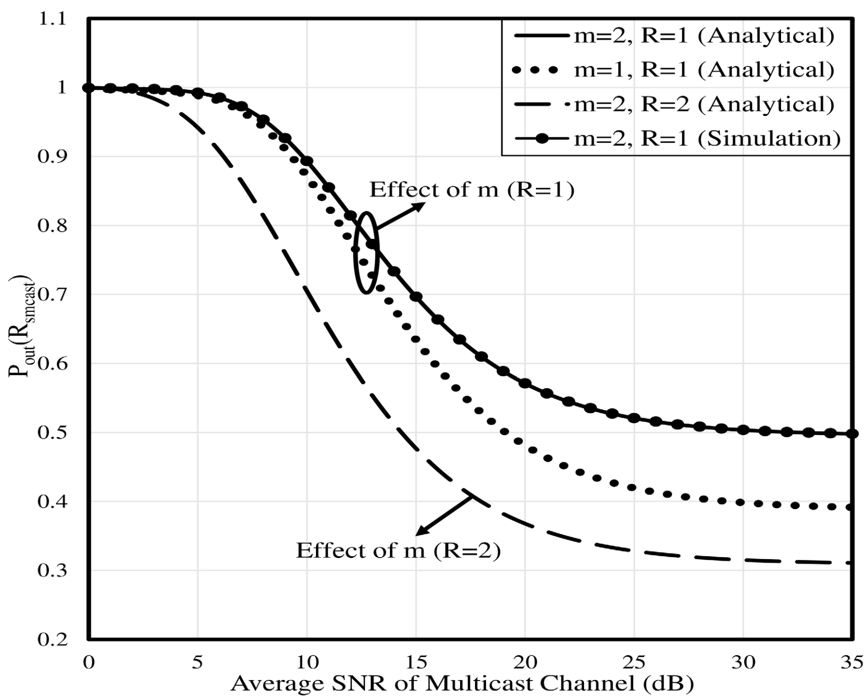

Figure 9. The effects of m and R on the $P_{out}\left(R_{smcast}\right)$ for $M=1$, $N=1$, $\mu=1$, $\kappa=1$, $R_s=0.9$ and $\gamma=1$ dB.

Therefore, based on the closed-form analytical expressions for the $Pr\left(C_{smcast}>0\right)$ and the $P_{out}\left(R_{smcast}\right)$ and from the observations of numerical

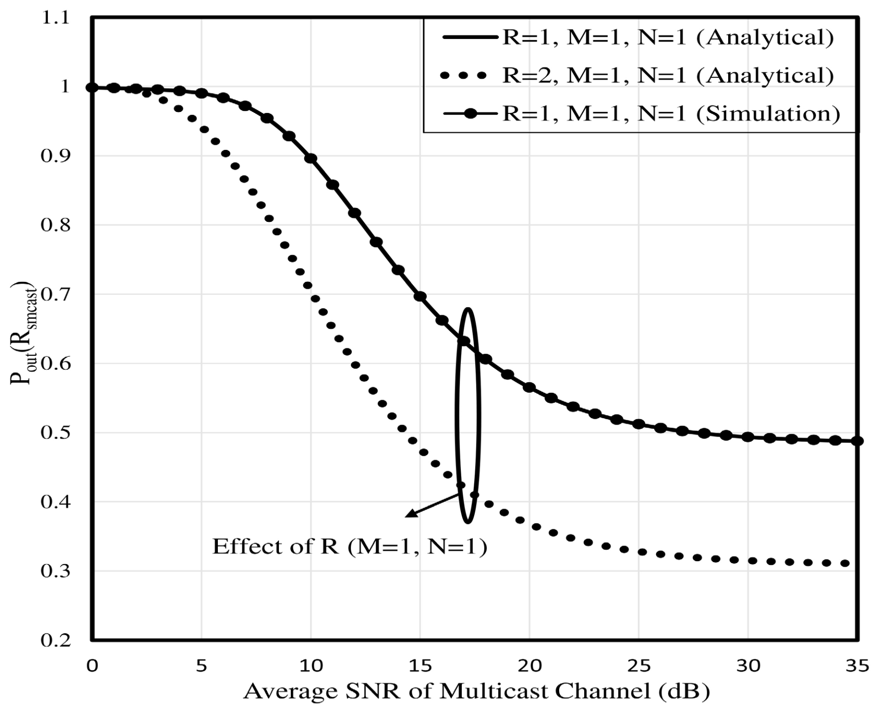

Figure 10. The effects of the number of relay, R, on the $P_{out}(R_{smcast})$ for $M=1$, $N=1$, $m=1$, $\mu=1$, $\kappa=1$, $R_s=0.9$ and $\gamma=1\,\text{dB}$.

results, the main findings of this paper can be summarized as follows: The $Pr(C_{smcast}>0)$ decreases with κ, μ, m, M and N. Therefore, increase in κ, μ, m, M and N degrades the security of the system. On the other hand, if R increases $Pr(C_{smcast}>0)$ increases and $P_{out}(R_{smcast})$ decreases. Therefore, increasing in R enhances the security of the system.

7. Conclusion

The creation of an analytical mathematical model to guarantee security in wireless multicasting using κ-μ shadowing fading channels with opportunistic relaying is the main topic of this article. The parameters such as κ, μ, m, the number of multicast users, eavesdroppers, and relays that assist in determining the values of N and R are used to derive the analytical formulas in the closed-form for the PNSMC and the SOPM. Our results conclude that the security in wireless multicasting through κ-μ fading channel degrades with the κ, μ, m, M and N. But increasing the number of relays helps to mitigate this loss of security which takes part in competition of opportunistic relaying technique to be the best relay. The effects of interferences on the security in multicasting through κ-μ shadowing fading channel are not considered in this paper. The zero-forcing precoding can be used to eliminate the effects of interferences and the selection and phase alignment precoding techniques can be used to enhance the security by using interference power. Finally, the validity of analytical expressions is verified via Monte-Carlo simulation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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