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Enhancing Security in Correlated Nakagami-*m* Fading Cellular Network Using SC and SSC Diversity Combining

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Abstract

The effect of correlated fading reduces the performance gain in multi-antenna communications. Diversity combining is a well-known technique to reduce the effect of correlation. But still, it is an open problem to quantify as the diversity scheme is more efficient in enhancing the security of cellular multicast network mitigating the effects of correlation. Motivated by this issue, this paper considers a secure wireless multicasting scenario through correlated cellular networks in the presence of multiple eavesdroppers. The selection combining (SC) and switch and stay combining (SSC) techniques are considered in dual arbitrarily correlated Nakagami-*m* fading channels. The closed-form analytical expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting are derived to understand the insight into the effects of correlation on the SC and SSC diversity schemes and to quantify which diversity scheme is more efficient in enhancing the security of correlated multicast networks. The results show that, although the diversity gain reduces the effect of correlation, the diversity gain provided by the SC diversity scheme is more significant in mitigating the effect of correlation compared to the SSC diversity scheme. Due to the selection mechanism of SC diversity, it is more sensitive to the change of SNR of the eavesdropper's channel compared to the case of the SSC diversity scheme.

Keywords

Arbitrarily Correlated Nakagami-*m* Fading, Cellular Multicast Channel, Probability of Non-Zero Secrecy Multicast Capacity, SC and SSC Diversity Schemes, Secure Outage Probability for Multicasting

1. Introduction

An important limitation to the capacity of wireless communication systems is a correlation, which mostly depends upon the antenna spacing of multi-antenna systems [1]. Likewise, it has recently been also proved that the effect of correlation decreases the diversity gain [2]. However, diversity combining techniques are the traditional means to combat the effects of correlation significantly. On the other hand, multicasting is an efficient wireless communication technique for group-oriented and personal communication such as video-conferencing, e-learning, etc. Due to the increase in application areas and the mobility of users with network components, security is a crucial aspect of wireless multicasting systems because the medium of wireless multicasting is susceptible to eavesdropping and fraud [3]. Therefore, the explosive growth of wireless multicasting services inevitably renders security into a challenging quality of service constraint that must be accounted for in the design of wireless multicasting networks.

Mitigating the effects of correlation, the enhancing security in multicasting through correlated fading channels is also a challenging task for the researchers in this field. Since the diversity combining techniques are the efficient means to combat the effects of correlation significantly, it is well recognized that the security in the correlated multicast networkscan be improved by employing diversity combining techniques.

A. Related Works

Recently, Shrestha *et al.* [4] studied a secure wireless multicasting scenario through a quasi-static Rayleigh fading channel in the presence of multiple eavesdroppers where each eavesdropper was equipped with multiple antennas. Authors showed that the physical layer security could be achieved even in the presence of multiple multi-antenna eavesdroppers. But authors did not consider the effect of correlation on the security in multicasting. In [5] [6], Giti *et al.* respectively used selective precoding and phase alignment precoding to enhance the security in multicasting by eliminating interference power. Sayed *et al.* [7] studied a secure wireless multicasting scenarios through multi-cellular multiple-input multiple-output (MIMO) networks with linear equalization and investigated the effect of interference on the distributed and co-located MIMO channels. But authors did not consider the effect of correlation and the method that can be used to reduce the effect of correlation. An iterative algorithm was used by Nguyen *et al.* [8] to enhance the security in cooperative cognitive radio multicast networks. The opportunistic relaying technique was also used by Nguyen *et al.* [9] to study the security of a half-duplex cognitive radio network. But authors did not consider the effects of correlation on the security analysis of multicasting. Kundu *et al.* [10] studied secure wireless multicasting through Generalized-K fading channels and derived the closed-form analytical expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting without considering the effects of correlation. Borshon *et al.* [11]

investigated the effects of Weibull fading parameter on the security in multicasting. In [12], A. S. M. Badrudduza and M. K. Kundu investigated the effects of $\kappa-\mu$ fading parameters on the security in a multicasting scenario. Atallah and Kaddoum [13] used partial cooperation to enhance the security in wireless networks in the presence of passive eavesdroppers. Sultana *et al.* [14] enhanced the security in cognitive radio multicast network using interference power. But authors did not consider the effects of correlation on the security of multicasting and did not use any technique to eliminate the effects of correlation. In [15], the opportunistic relaying technique was used by Kibria *et al.* to enhance the security in multicasting without considering the effects of correlation. Sun *et al.* [16] investigated the impact of antenna correlation on the security of single-input multiple-output (SIMO) channel in the presence of multiple eavesdroppers. But authors used a unicasting scenario to investigate that effect and did not consider the effect of correlation on the multicasting network. In [17], Badrudduza *et al.* used the opportunistic relaying technique to reduce the effect of correlation on the security in multicasting over Nakagami-m fading channels. The authors did not mention the method that can be used to reduce that effect of correlation and which method is more efficient.

B. Existing Research Gap

Based on the aforementioned scenario available in the literature, it is observed that the compensation of the loss of security due to correlation in multicellular interference network using 1) diversity combining and 2) opportunistic relaying is still an open problem. Moreover, the performance comparison of different diversity combining techniques is an important issue to know, which combining technique is more significant for enhancing security in multicellular interference network mitigating the effect of correlation.

C. Contributions

Motivated by the aforementioned research gap in the literature and the importance of security in practical multicasting, in this paper, the authors studied a multicasting scenario through a cellular network and developed the mathematical model to ensure its security considering the effect of correlation. The authors use SC and SSC diversity schemes and compare their performance in enhancing security in correlated cellular networks and mitigating the effects of correlation. The major contributions of this paper can be summarized as follows.

- Based on the PDFs of dual arbitrarily correlated Nakagami-m fading channel with SC and SSC diversity schemes, at first, authors derive the expressions for the PDFs of the SNR of each multicast user and eavesdropper considering the effect of correlation.
- Secondly, using these PDFs of SNRs, the authors derive the PDFs of multicast channel and eavesdropper channel.
- Thirdly, the authors use the PDFs of multicast channel and eavesdropper channel to derive the analytical expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting.

- Finally, authors investigate the effect of correlation on the SC and SSC diversity schemes and quantify, which diversity scheme is more efficient in enhancing the security of cellular multicast network by mitigating the effects of correlation.

The remainder of this paper is organized as follows. Sections 2 and 3 describe the system model and problem formulation, respectively. The expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting are derived respectively in Sections 4 and 5. Numerical results are presented in Section 6. Finally, Section 7 draws the conclusions of this work.

2. System Model

A confidential wireless multicasting scenario shown in **Figure 1** is considered in which a base station (BS) communicates with a group of M multicast users in the presence of N eavesdroppers. The BS is equipped with single antenna, and each multicast user and eavesdropper are equipped with n_r and n_e antennas, respectively. The antennas of multicast users and eavesdroppers are correlated with coefficient ρ. The transmitter transmits x with power P to the destination users M, and N eavesdroppers try to decode the transmitted signal. Let $\mathbf{y}_{d_i}$ and $\mathbf{y}_{e_j}$ are the received signals at the ith ($i = 1, \cdots, M$) destination user and jth ($j = 1, \cdots, N$) eavesdropper, respectively. Then, we have

$$\mathbf{y}_{d_i} = \mathbf{h}_i x + \mathbf{z}_{d_i}, \tag{1}$$

$$\mathbf{y}_{e_i} = \mathbf{g}_j x + \mathbf{z}_{e_j}, \tag{2}$$

where $\mathbf{h}_i \in \mathbb{C}^{n_r \times 1}$ and $\mathbf{g}_j \in \mathbb{C}^{n_e \times 1}$ denote the channel coefficients from BS to ith destination user, and to jth eavesdropper, respectively. $\mathbf{z}_{d_i} \sim \tilde{\mathcal{N}}(0, N_d)$ and $\mathbf{z}_{d_j} \sim \tilde{\mathcal{N}}(0, N_e)$ denote the additive white Gaussian noise (AWGN) at the ith destination user, and jth eavesdropper with zero mean and variances N_d and

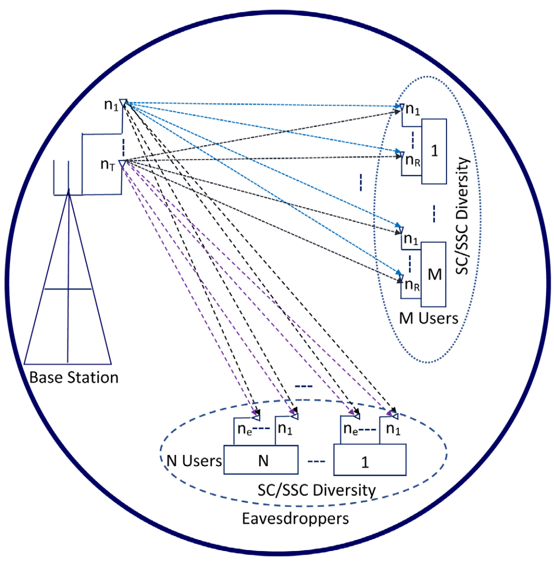

Figure 1. System model.

N_e, respectively. The instantaneous signal-to-noise ratio (SNR) at the *i*th destination user and *j*th eavesdropper can be expressed as $\gamma_{d_i} = \frac{P}{N_d}\|\mathbf{h}_i\|^2$ and $\gamma_{e_j} = \frac{P}{N_e}\|\mathbf{g}_j\|^2$, respectively.

3. Problem Formulation

In this section, authors derive the expressions for the probability density functions (PDFs) of the SNRs of multicast channels and eavesdropper channels based on the PDFs of SNRs of *i*th destination user and *j*th eavesdropper with SC and SSC diversity schemes, respectively.

A. The PDF of γ_{d_i} and γ_{e_j}

Let $f_{\gamma_{d_i}}^{SC}(\gamma_i)$ and $f_{\gamma_{e_j}}^{SC}(\gamma_j)$ denotes the PDFs of γ_{d_i} and γ_{e_j} with SC, and $f_{\gamma_{d_i}}^{SSC}(\gamma_i)$ and $f_{\gamma_{e_j}}^{SSC}(\gamma_j)$ denotes the PDFs of γ_{d_i} and γ_{e_j} with SSC diversity schemes, respectively.

1) PDF with SC diversity: Since the SC scheme chooses the highest SNR's branch using the relationship $\gamma_{d_i} = \max\left\{\gamma_{d_{i,k}}, k = 1, 2, \cdots, n_r\right\}$, therefore the PDF of γ_{d_i} for dual arbitrary correlated Nakagami-*m* fading channel with SC diversity is given by [18]

$$f_{\gamma_{d_i}}^{SC}(\gamma_i) = \frac{2m^m \overline{\gamma}_m^{-m} \gamma_i^{m-1} e^{-\frac{m\gamma_i}{\overline{\gamma}_m}}}{\Gamma(m)\left\{1 - Q_m\left(\sqrt{2\alpha_{d_i}\rho\gamma_i}, \sqrt{2\alpha_{d_i}\gamma_i}\right)\right\}^{-1}}, \tag{3}$$

where $\alpha_{d_i} = \frac{m}{\overline{\gamma}_i(1-\rho)}$, m denotes the Nakagami-*m* fading parameter and $Q_m(.,.)$ is the first order Marcum Q-function defined as

$$Q_m(a,b) = 1 - \exp\left(-\frac{a^2}{2}\right)\sum_{k=0}^{\infty}\frac{a^2\gamma\left(m+k, \frac{b^2}{2}\right)}{2k!\,\Gamma(m+k)} \tag{4}$$

Using the identity of Equation (4), the expression of $f_{\gamma_{d_i}}^{SC}(\gamma_i)$ can be written as

$$f_{\gamma_{d_i}}^{SC}(\gamma_i) = \frac{2m^m}{\Gamma(m)\overline{\gamma}_m^m}\sum_{k=0}^{\infty}\frac{\alpha_{d_i}\rho}{k!}\left[\frac{\gamma_i^{m+k-1}}{e^{\left(\frac{m}{\overline{\gamma}_m}+\alpha_{d_i}\rho\right)\gamma_i}} - \sum_{l=0}^{m+k-l}\frac{\alpha_{d_i}^l \gamma_i^{m+k+l-1}}{l!\,e^{\left(\frac{m}{\overline{\gamma}_m}+\alpha_{d_i}\rho+\alpha_{d_i}\right)\gamma_i}}\right] \tag{5}$$

Similarly, the PDF of γ_{e_j} for dual arbitrary correlated Nakagami-*m* fading channel with SC diversity is given by,

$$f_{\gamma_{e_j}}^{SC}(\gamma_j) = \frac{2m^m}{\Gamma(m)\overline{\gamma}_e^m}\sum_{k=0}^{\infty}\frac{\alpha_{d_j}\rho}{k!}\left[\frac{\gamma_j^{m+k-1}}{e^{\left(\frac{m}{\overline{\gamma}_e}+\alpha_{d_j}\rho\right)\gamma_j}} - \sum_{l=0}^{m+k-l}\frac{\alpha_{d_j}^l \gamma_j^{m+k+l-1}}{l!\,e^{\left(\frac{m}{\overline{\gamma}_e}+\alpha_{d_j}\rho+\alpha_{d_j}\right)\gamma_j}}\right] \tag{6}$$

2) PDF with SSC diversity: Since the SSC diversity scheme selects a particular diversity branch until its SNR drops a predetermined threshold value, therefore, the PDF of SNR with SSC diversity can be defined considering two cases such as, when 1) $\gamma \le \gamma_T$ and 2) $\gamma > \gamma_T$, where γ_T denotes the threshold SNR. Hence, the PDF of γ_{d_i} for dual arbitrary correlated Nakagami-m fading channel with SSC diversity is given by [18]

$$f_{\gamma_{d_i}}^{SSC}(\gamma_i) = \begin{cases} D(\gamma_i), & \text{if } \gamma_i \le \gamma_T \\ D(\gamma_i) + V_d(\gamma_i), & \text{if } \gamma_i > \gamma_T, \end{cases} \tag{7}$$

where $V_d(\gamma_i) = \dfrac{m^m \gamma_i^{m-1} \mathrm{e}^{-\frac{m\gamma_i}{\bar{\gamma}_m}}}{\Gamma(m)\bar{\gamma}_m^m}$ and

$D(\gamma_i) = \dfrac{m^m \bar{\gamma}_m^{-m} \gamma_i^{m-1} \mathrm{e}^{-\frac{m\gamma_i}{\bar{\gamma}_m}}}{\Gamma(m)\left\{1 - Q_m\left(\sqrt{2\alpha_{d_i}\rho\gamma_i}, \sqrt{2\alpha_{d_i}\rho\gamma_T}\right)\right\}^{-1}}$. Using the identity of Equation (4), the expressions of $f_{\gamma_{d_i}}^{SSC}(\gamma_i)$ can be written as

$$f_{\gamma_{d_i}}^{SSC}(\gamma_i) = \begin{cases} V_d(\gamma_i) \times B_d(\gamma_i), & \text{if } \gamma_i \le \gamma_T \\ V_d(\gamma_i)\left[1 + B_d(\gamma_i)\right], & \text{if } \gamma_i > \gamma_T, \end{cases} \tag{8}$$

where $B_d(\gamma_i) = \mathrm{e}^{-\alpha_{d_i}\rho\gamma_i} \sum_{k=0}^{\infty} \left(\alpha_{d_i}\rho\gamma_i\right)^k \dfrac{\gamma(m+k, \gamma_T)}{k!\Gamma(m+k)}$. Similarly, the expression of $f_{\gamma_{e_j}}^{SSC}(\gamma_j)$ can be expressed as

$$f_{\gamma_{e_j}}^{SSC}(\gamma_j) = \begin{cases} V_e(\gamma_j) \times B_e(\gamma_j), & \text{if } \gamma_j \le \gamma_T \\ V_e(\gamma_j)\left[1 + B_e(\gamma_j)\right], & \text{if } \gamma_j > \gamma_T, \end{cases} \tag{9}$$

where $V_e(\gamma_j) = \dfrac{m^m \gamma_j^{m-1} \mathrm{e}^{-\frac{m\gamma_j}{\bar{\gamma}_e}}}{\Gamma(m)\bar{\gamma}_e^m}$ and

$B_e(\gamma_j) = \mathrm{e}^{-\alpha_{e_j}\rho\gamma_j} \sum_{k=0}^{\infty} \left(\alpha_{e_j}\rho\gamma_j\right)^k \dfrac{\gamma(m+k, \gamma_T)}{k!\Gamma(m+k)}$.

B. The PDF of SNR for Multicast Channels

Let $d_{\min} \triangleq \min_{1 \le i \le M} \gamma_{d_i}$, then the PDF of $d_{\min}$ can be defined as [19] [20]

$$f_{d_{\min}}(\gamma_i) = M f_{\gamma_{d_i}}(\gamma_i)\left[1 - F_{\gamma_{d_i}}(\gamma_i)\right]^{M-1} = M f_{\gamma_{d_i}}(\gamma_i)\left[1 - \int_0^{\gamma_i} f_{\gamma_{d_i}}(\gamma_i)\mathrm{d}\gamma_i\right]^{M-1}, \tag{10}$$

where $F_{\gamma_{d_i}}(\gamma_i)$ denotes the cumulative distribution function (CDF) of γ_{d_i}.

1) The PDF of $d_{\min}$ with SC diversity: Let $f_{d_{\min}}^{SC}(\gamma_i)$ denotes the PDF of $d_{\min}$ with SC diversity. Then, $f_{d_{\min}}^{SC}(\gamma_i)$ can be defined as

$$f_{d_{\min}}^{SC}(\gamma_i) = M f_{\gamma_{d_i}}^{SC}(\gamma_i)\left[1 - \int_0^{\gamma_i} f_{\gamma_{d_i}}^{SC}(\gamma_i)\mathrm{d}\gamma_i\right]^{M-1}. \tag{11}$$

Substituting the value of $f_{\gamma_{d_i}}^{SC}(\gamma_i)$ in Equation (11) and using the following identities of [21] stated in Equations (3.351.2) and (1.111),

$$\int_0^u x^n \mathrm{e}^{-\mu x}\mathrm{d}x = \frac{n!}{\mu^{n+1}} - \mathrm{e}^{-\mu u}\sum_{k=0}^{n} \frac{n! u^k}{k! \mu^{n-k+1}}, \tag{12}$$

$$(a+x)^n = \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k}, \tag{13}$$

the expression of $f_{d_{\min}}^{SC}(\gamma_i)$ can be derived as

$$f_{d_{\min}}^{SC}(\gamma_i) = M\mathcal{W}_d\mathcal{T}_d\left(\frac{\gamma_i^{\phi_1}}{\mathrm{e}^{\varphi_1\gamma_i}} - \mathcal{R}_d\frac{\gamma_i^{\psi_1}}{\mathrm{e}^{\nu_1\gamma_i}}\right), \tag{14}$$

where the expression of $\mathcal{W}_d$ is shown in Equation (15) at the bottom of the next page, $\mathcal{T}_d = \delta\sum_{k=0}^{\infty}\frac{\alpha_{d_i}\rho}{k!}$, $\mathcal{R}_d = \sum_{l=0}^{m+k-l}\frac{\alpha_{d_i}^l}{l!}$, $\phi_1 = m+k-1+k_1(l_1-l_2)+k_2l_2$, $\varphi_1 = \left(\frac{m}{\bar{\gamma}_m}+\alpha_{d_i}\rho\right)(l_1-2l_2-1)+\alpha_{d_i}l_2$, $\psi_1 = m+k+m-1+k_1(l_1-l_2)+k_2l_2$, $\nu_1 = \left(\frac{m}{\bar{\gamma}_m}+\alpha_{d_i}\rho\right)(l_1-l_2+1)+\alpha_{d_i}(1+l_2)$, $\theta_1 = \frac{(m+k-1)!}{\left(\frac{m}{\bar{\gamma}_m}+\alpha_{d_i}\rho\right)^{m+k}}$,

$\theta_3 = \frac{(k+l+m-1)!}{\left(\frac{m}{\bar{\gamma}_m}+\alpha_{d_i}\rho\right)^{k+l+m}}$ and $\delta = \frac{2m^m}{\Gamma(m)\bar{\gamma}_m^m}$.

$$\mathcal{W}_d = \sum_{l_1=0}^{M-1}\frac{(M-1)!\{1-\mathcal{T}_d(\theta_1-\mathcal{R}_d\theta_3)\}^{M-1-l}}{(M-1-l_1)!}\sum_{l_2=0}^{l_1}\frac{l_1!\mathcal{T}_d^{l_1-2l_2}\mathcal{R}_d^{l_2}\theta_2^{l_1-l_2}\theta_4^{l_2}(-1)^{l_2}}{(l_1-l_2)!} \tag{15}$$

2) The PDF of $d_{\min}$ with SSC diversity: Let $f_{d_{\min}}^{SSC}(\gamma_i)$ denotes the PDF of $d_{\min}$ with SSC diversity. Then, $f_{d_{\min}}^{SSC}(\gamma_i)$ can be defined as

$$\begin{aligned} f_{d_{\min}}^{SSC}(\gamma_i) &= Mf_{\gamma_{d_i}}^{SSC}(\gamma_i)\left[1-\int_0^{\gamma_i} f_{\gamma_{d_i}}^{SSC}(\gamma_i)\mathrm{d}\gamma_i\right]^{M-1} \\ &= Mf_{\gamma_{d_i}}^{SSC}(\gamma_i)\left[1-\int_0^{\gamma_i}V_d(\gamma_i)B_d(\gamma_i)\mathrm{d}\gamma_i-\int_0^{\gamma_i}V_d(\gamma_i)\mathrm{d}\gamma_i\right]^{M-1} \end{aligned} \tag{16}$$

In order to simplify, only the case of $\gamma_i > \gamma_T$ is considered to derived the expression of $f_{d_{\min}}^{SSC}(\gamma_i)$. Substituting the value of $f_{\gamma_{d_i}}^{SSC}(\gamma_i)$ in Equation (16) and using the identities of Equations (12) and (13), the expression of $f_{d_{\min}}^{SSC}(\gamma_i)$ can be written as

$$f_{d_{\min}}^{SSC}(\gamma_i) = M\mathcal{W}_d\mathcal{T}_d\left[\frac{\gamma_i^{\phi_1}}{\mathrm{e}^{\varphi_1\gamma_i}} - \mathcal{R}_d\frac{\gamma_i^{\psi_1}}{\mathrm{e}^{\nu_1\gamma_i}} - \frac{\delta}{2}\left\{\kappa_d - \mathrm{e}^{-\left(\frac{m}{\bar{\gamma}_m}\right)\gamma_i}\sum_{k=0}^{m-1}\frac{\kappa_d\gamma_i^k\left(\frac{m}{\bar{\gamma}_m}\right)^k}{k!}\right\}\right], \tag{17}$$

where $\kappa_d = \frac{(m-1)!}{\left(\frac{m}{\bar{\gamma}_m}\right)^m}$.

C. The PDF of SNR for Eavesdropper Channels

Let $d_{\max} \triangleq \max_{1\le j\le N}\gamma_{e_j}$, then the PDF of $d_{\max}$ can be defined as [3] [19]

$$f_{d_{\max}}(\gamma_j) = Nf_{\gamma_{e_j}}(\gamma_j)\left[F_{\gamma_{e_j}}(\gamma_j)\right]^{N-1} = Nf_{\gamma_{e_j}}(\gamma_j)\left[\int_0^{\gamma_j} f_{\gamma_{e_j}}(\gamma_j)\mathrm{d}\gamma_j\right]^{N-1}, \tag{18}$$

where $F_{\gamma_{e_j}}(\gamma_j)$ denotes the CDF of γ_{e_j}.

1) PDF with SC diversity

Let $f_{d_{\max}}^{SC}(\gamma_j)$ denotes the PDF of $d_{\max}$ with SC diversity. Then, $f_{d_{\max}}^{SC}(\gamma_j)$ can be defined as

$$f_{d_{\max}}^{SC}(\gamma_j) = N f_{\gamma_{e_j}}^{SC}(\gamma_j)\left[\int_0^{\gamma_j} f_{\gamma_{e_j}}^{SC}(\gamma_j)\mathrm{d}\gamma_j\right]^{N-1}. \tag{19}$$

Substituting the value of $f_{\gamma_{e_j}}^{SC}(\gamma_j)$ in Equation (19) and using the identities of Equations (12) and (13), the expression of $f_{d_{\max}}^{SC}(\gamma_j)$ can be derived as

$$f_{d_{\max}}^{SC}(\gamma_j) = N\mathcal{W}_e\mathcal{T}_e\left(\frac{\gamma_j^{\phi_2}}{\mathrm{e}^{\varphi_2\gamma_j}} - \mathcal{R}_e\frac{\gamma_j^{\psi_2}}{\mathrm{e}^{\nu_2\gamma_j}}\right), \tag{20}$$

where the expression of $\mathcal{W}_e$ is shown in Equation (21) at the bottom of the next page, $\mathcal{T}_e = \xi\sum_{k=0}^{\infty}\frac{\alpha_{e_j}\rho}{k!}$, $\mathcal{R}_e = \sum_{l=0}^{m+k-l}\frac{\alpha_{e_j}^l}{l!}$, $\phi_2 = m+k-1+k_1(l_1-l_2)+k_2l_2$,
$\varphi_2 = \left(\frac{m}{\overline{\gamma}_e}+\alpha_{e_j}\rho\right)(l_1-2l_2-1)+\alpha_{e_j}l_2$, $\psi_2 = m+k+m-1+k_1(l_1-l_2)+k_2l_2$,
$\nu_2 = \left(\frac{m}{\overline{\gamma}_e}+\alpha_{e_j}\rho\right)(l_1-l_2+1)+\alpha_{e_j}(1+l_2)$, $\theta_2 = \frac{(m+k-1)!}{\left(\frac{m}{\overline{\gamma}_e}+\alpha_{e_j}\rho\right)^{m+k}}$,
$\theta_4 = \frac{(k+l+m-1)!}{\left(\frac{m}{\overline{\gamma}_e}+\alpha_{e_j}\rho\right)^{k+l+m}}$ and $\xi = \frac{2m^m}{\Gamma(m)\overline{\gamma}_e^m}$.

$$\mathcal{W}_e = \sum_{l_1=0}^{N-1}\frac{(N-1)!\left\{1-\mathcal{T}_d\left(\theta_2-\mathcal{R}_e\theta_4\right)\right\}^{N-1-l}}{(N-1-l_1)!}\sum_{l_2=0}^{l_1}\frac{l_1!\,\mathcal{T}_e^{l_1-2l_2}\mathcal{R}_e^{l_2}\theta_2^{l_1-l_2}\theta_4^{l_2}(-1)^{l_2}}{(l_1-l_2)!} \tag{21}$$

2) PDF with SSC diversity: Let $f_{d_{\max}}^{SSC}(\gamma_j)$ denotes the PDF of $d_{\max}$ with SSC diversity. Then, $f_{d_{\max}}^{SSC}(\gamma_j)$ can be defined as

$$\begin{aligned} f_{d_{\max}}^{SSC}(\gamma_j) &= N f_{\gamma_{e_j}}^{SSC}(\gamma_j)\left[\int_0^{\gamma_j} f_{\gamma_{e_j}}^{SSC}(\gamma_j)\mathrm{d}\gamma_j\right]^{N-1} \\ &= N f_{\gamma_{e_j}}^{SSC}(\gamma_j)\left[\int_0^{\gamma_j} V_e(\gamma_j)B_e(\gamma_j)\mathrm{d}\gamma_j - \int_0^{\gamma_j} V_e(\gamma_j)\mathrm{d}\gamma_j\right]^{N-1} \end{aligned} \tag{22}$$

Substituting the value of $f_{\gamma_{e_j}}^{SSC}(\gamma_j)$ in Equation (22) and using the identities of Equations (12) and (13), the expression of $f_{d_{\max}}^{SSC}(\gamma_j)$ is given by,

$$f_{d_{\max}}^{SSC}(\gamma_j) = N\mathcal{W}_e\mathcal{T}_e\left[\frac{\gamma_j^{\phi_2}}{\mathrm{e}^{\varphi_2\gamma_j}} - \mathcal{R}_e\frac{\gamma_j^{\psi_2}}{\mathrm{e}^{\nu_2\gamma_j}} - \frac{\xi}{2}\left\{\kappa_e - \mathrm{e}^{-\left(\frac{m}{\overline{\gamma}_e}\right)\gamma_j}\sum_{k=0}^{m-1}\frac{\kappa_e\gamma_j^k\left(\frac{m}{\overline{\gamma}_e}\right)^k}{k!}\right\}\right], \tag{23}$$

where $\kappa_e = \frac{(m-1)!}{\left(\frac{m}{\overline{\gamma}_e}\right)^m}$.

4. Probability of Non-Zero Secrecy Multicast Capacity

The probability of non-zero secrecy multicast capacity can be defined as

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

A. $Pr\left(C_{smcast}>0\right)$ with SC diversity

Let $Pr\left(C_{smcast}>0\right)_{SC}$ denotes the probability of non-zero secrecy multicast capacity with SC diversity, then $Pr\left(C_{smcast}>0\right)_{SC}$ is defined as

$$Pr\left(C_{smcast}>0\right)_{SC}=\int_0^{\infty} f_{d_{\min}}^{SC}\left(\gamma_i\right)\int_0^{\gamma_i} f_{d_{\max}}^{SC}\left(\gamma_j\right)\mathrm{d}\gamma_j\mathrm{d}\gamma_i \tag{25}$$

Substituting the values of $f_{d_{\min}}^{SC}\left(\gamma_i\right)$ and $f_{d_{\max}}^{SC}\left(\gamma_j\right)$ in Equation (25) and performing integration, the closed-form analytical expression for $Pr\left(C_{smcast}>0\right)_{SC}$ is given in Equation (26) at the bottom of this page, where

$\mathcal{K}_1=\sum_{t_1=0}^{N-1}\frac{(N-1)!\left(\mathcal{T}_e\vartheta_1-\mathcal{R}_e\vartheta_3\right)^{N-1-t_1}}{\left(N-1-t_1\right)!}$, $D_1=\frac{\phi_2!}{\varphi_2^{\phi_2+1}}-\frac{\mathcal{R}_e\psi_2!}{\nu_2^{\psi_2+1}}$,

$D_2=\sum_{u_1=0}^{\phi_2}\frac{\phi_2!}{u_1!\varphi_2^{\phi_2-u_1+1}}$, $D_3=\mathcal{R}_e\sum_{u_2=0}^{\psi_2}\frac{\psi_2!}{u_2!\nu_2^{\psi_2-u_2+1}}$, $\vartheta_1=\frac{(m+k-1)!}{\varphi_2^{m+k}}$,

$\vartheta_3=\frac{(m+k+l-1)!}{\left(\varphi_2+a_{e_j}\right)^{m+k+l}}$,

$$\begin{aligned}&Pr\left(C_{smcast}>0\right)_{SC}\\&=MN\mathcal{W}_d\mathcal{W}_e\mathcal{T}_d\mathcal{T}_e\mathcal{K}_1\left[D_3\left\{\frac{\left(u_2+\phi_1\right)!}{\left(\varphi_1+\nu_2\right)^{u_2+\phi_1+1}}-\mathcal{R}_d\frac{\left(u_2+\psi_1\right)!}{\left(\nu_1+\nu_2\right)^{u_2+\psi_1+1}}\right\}\right.\\&\left.+D_1\left\{\frac{\phi_1!}{\varphi_1^{\phi_1+1}}-\mathcal{R}_d\frac{\psi_1!}{\nu_1^{\psi_1+1}}\right\}-D_2\left\{\frac{\left(u_1+\phi_1\right)!}{\left(\varphi_1+\varphi_2\right)^{u_1+\phi_1+1}}-\mathcal{R}_d\frac{\left(u_1+\psi_1\right)!}{\left(\nu_1+\varphi_2\right)^{u_1+\psi_1+1}}\right\}\right]\end{aligned} \tag{26}$$

B. $Pr\left(C_{smcast}>0\right)$ with SSC Diversity

Let $Pr\left(C_{smcast}>0\right)_{SSC}$ denotes the probability of non-zero secrecy multicast capacity with SSC diversity, then $Pr\left(C_{smcast}>0\right)_{SSC}$ is defined as

$$Pr\left(C_{smcast}>0\right)_{SSC}=\int_0^{\infty} f_{d_{\min}}^{SSC}\left(\gamma_i\right)\int_0^{\gamma_i} f_{d_{\max}}^{SSC}\left(\gamma_j\right)\mathrm{d}\gamma_j\mathrm{d}\gamma_i \tag{27}$$

Substituting the values of $f_{d_{\min}}^{SSC}\left(\gamma_i\right)$ and $f_{d_{\max}}^{SSC}\left(\gamma_j\right)$ in Equation (27) and performing integration using the following identity of [21] stated in Equations (3.351.3), the closed-form analytical expression for $Pr\left(C_{smcast}>0\right)_{SSC}$ is given in Equation (28) at the bottom of the nest page,

$$\int_0^{\infty} x^n \mathrm{e}^{-\mu x}\mathrm{d}x=n!\mu^{-(n+1)},$$

where $D_4=\frac{\delta k_d}{2}-\sum_{k=0}^{m-1}\frac{k_d\mu_d^k\delta}{2k!}$, $D_5=\frac{\delta k_e}{2}-\sum_{k=0}^{m-1}\frac{k_e\mu_e^k\xi}{2k!}$,

$D_6=\frac{k!}{\mu_e^{k+1}}-\sum_{d_3=0}^{k}\frac{k!}{d_3!\mu_e^{k-d_3+1}}$, $\mu_d=\frac{m}{\bar{\gamma}_m}$ and $\mu_e=\frac{m}{\bar{\gamma}_e}$.

$$\begin{aligned}&Pr\left(C_{smcast}>0\right)_{SSC}\\&=MN\mathcal{W}_d\mathcal{W}_e\mathcal{T}_d\mathcal{T}_e\mathcal{K}_1\left[D_3\left\{\frac{(u_2+\phi_1)!}{(\varphi_1+\nu_2)^{u_2+\phi_1+1}}-\mathcal{R}_d\frac{(u_2+\psi_1)!}{(\nu_1+\nu_2)^{u_2+\psi_1+1}}\right\}\right.\\&+D_1\left\{\frac{\phi_1!}{\varphi_1^{\phi_1+1}}-\mathcal{R}_d\frac{\psi_1!}{\nu_1^{\psi_1+1}}\right\}-D_2\left\{\frac{(u_1+\phi_1)!}{(\varphi_1+\varphi_2)^{u_1+\phi_1+1}}-\mathcal{R}_d\frac{(u_1+\psi_1)!}{(\nu_1+\varphi_2)^{u_1+\psi_1+1}}\right\}\\&\left.-D_4D_5D_6\frac{(k+d_3)!}{(\mu_d+\mu_e)^{(k+d_3+1)}}\right]\end{aligned}\tag{28}$$

5. Secure Outage Probability for Multicasting

The secure outage probability for multicasting can be defined as

$$P_{out}\left(R_{smcast}\right)=1-\int_0^\infty f_{d_{\max}}\left(\gamma_j\right)\left\{\int_\lambda^\infty f_{d_{\min}}\left(\gamma_i\right)\mathrm{d}\gamma_i\right\}\mathrm{d}\gamma_j,\tag{29}$$

where $\lambda=\mathrm{e}^{2R_{smcast}\left(1+\gamma_j\right)-1}$ and R_{smcast} denotes the target secrecy multicast rate.

A. $P_{out}\left(R_{smcast}\right)$ with SC diversity

Let $P_{out}\left(R_{smcast}\right)_{SC}$ denotes the secure outage probability for multicasting with SC diversity, then $P_{out}\left(R_{smcast}\right)_{SC}$ is defined as

$$P_{out}\left(R_{smcast}\right)_{SC}=1-\int_0^\infty f_{d_{\max}}^{SC}\left(\gamma_j\right)\left\{\int_\lambda^\infty f_{d_{\min}}^{SC}\left(\gamma_i\right)\mathrm{d}\gamma_i\right\}\mathrm{d}\gamma_j.\tag{30}$$

Substituting the values of $f_{d_{\min}}^{SC}\left(\gamma_i\right)$ and $f_{d_{\max}}^{SC}\left(\gamma_j\right)$ in Equation (30) and performing integration, the closed-form analytical expression for $P_{out}\left(R_{smcast}\right)_{SC}$ is given in Equation (31) at the bottom of the next page, where

$$L_1=\sum_{a_1=0}^{\phi_1}\frac{\phi_1!}{a_1!\varphi_1^{\phi_1-a_1+1}}\sum_{d_1=0}^{a_1}\frac{a_1!\left(-1+\mathrm{e}^{2R_{smcast}}\right)^{a_1-d_1}}{(a_1-d_1)!}\exp\left(\varphi_1-\varphi_1\mathrm{e}^{2R_{smcast}}+2R_{smcast}a_1\right)$$

$$L_2=\sum_{a_2=0}^{\psi_1}\frac{\psi_1!}{a_2!\nu_1^{\psi_1-a_2+1}}\sum_{d_2=0}^{a_2}\frac{a_2!\left(-1+\mathrm{e}^{2R_{smcast}}\right)^{a_2-d_2}}{(a_2-d_2)!}\exp\left(\nu_1-\nu_1\mathrm{e}^{2R_{smcast}}+2R_{smcast}a_2\right)$$

$$\begin{aligned}&P_{out}\left(R_{smcast}\right)_{SC}\\&=MN\mathcal{W}_d\mathcal{W}_e\mathcal{T}_d\mathcal{T}_e\mathcal{K}_1\left[\frac{L_1(\phi_2+a_1)!}{\left(\varphi_2+\varphi_1\mathrm{e}^{2R_s}\right)^{\phi_2+a_1+1}}-\frac{R_dL_2(\phi_2+a_2)!}{\left(\varphi_2+\nu_1\mathrm{e}^{2R_s}\right)^{\phi_2+a_2+1}}\right.\\&\left.-\frac{R_eL_1(\psi_2+a_1)!}{\left(\nu_2+\varphi_1\mathrm{e}^{2R_s}\right)^{\psi_2+a_1+1}}+\frac{R_dR_eL_2(\psi_2+a_2)!}{\left(\nu_2+\nu_1\mathrm{e}^{2R_s}\right)^{\psi_2+a_2+1}}\right]\end{aligned}\tag{31}$$

B. $P_{out}\left(R_{smcast}\right)$ with SSC diversity

Let $P_{out}\left(R_{smcast}\right)_{SSC}$ denotes the secure outage probability for multicasting with SSC diversity, then $P_{out}\left(R_{smcast}\right)_{SSC}$ is defined as

$$P_{out}\left(R_{smcast}\right)_{SSC}=1-\int_0^\infty f_{d_{\max}}^{SSC}\left(\gamma_j\right)\left\{\int_\lambda^\infty f_{d_{\min}}^{SSC}\left(\gamma_i\right)\mathrm{d}\gamma_i\right\}\mathrm{d}\gamma_j.\tag{32}$$

Substituting the values of $f_{d_{\min}}^{SSC}\left(\gamma_i\right)$ and $f_{d_{\max}}^{SSC}\left(\gamma_j\right)$ in Equation (32) and performing integration, the closed-form analytical expression for $P_{out}\left(R_{smcast}\right)_{SSC}$

is given in Equation (33) at the bottom of the next page,

$$\begin{aligned} &P_{out}\left(R_{smcast}\right)_{SSC} \\ &= MN\mathcal{W}_d\mathcal{W}_e\mathcal{T}_d\mathcal{T}_e\mathcal{K}_1\left[1+\frac{L_1\left(\phi_2+a_1\right)!}{\left(\varphi_2+\varphi_1\mathrm{e}^{2R_s}\right)^{\phi_2+a_1+1}}-\frac{R_dL_2\left(\phi_2+a_2\right)!}{\left(\varphi_2+\nu_1\mathrm{e}^{2R_s}\right)^{\phi_2+a_2+1}}\right. \\ &-\frac{R_eL_1\left(\psi_2+a_1\right)!}{\left(\nu_2+\varphi_1\mathrm{e}^{2R_s}\right)^{\psi_2+a_1+1}}+\frac{R_dR_eL_2\left(\psi_2+a_2\right)!}{\left(\nu_2+\nu_1\mathrm{e}^{2R_s}\right)^{\psi_2+a_2+1}} \\ &\left.-L_3 2\mu_m R_{smcast}\left(k+1\right)!\left(2d_3R_{smcast}\right)^{-(k+2)}\right] \end{aligned} \tag{33}$$

where $L_3=\sum_{d_3=0}^{k}\frac{(-1)^{k-d_3}(k!)^2}{d_3!(k-d_3)!}$ and $\mu_m=\mathrm{e}^{2d_3R_{smcast}}\left(2R_{smcast}-\mathrm{e}^{-\mu_d}\right)$.

6. Numerical Results

Figure 2 shows the probability of non-zero secrecy multicast capacity, $Pr\left(C_{smcast}>0\right)$, with SC and SSC diversity schemes, as a function of the average SNR of the multicast channel, $\overline{\gamma}_m$, with $\rho=0.5$. This figure shows the comparison between SC and SSC diversity schemes in terms of the effect of channel correlation, ρ, on the $Pr\left(C_{smcast}>0\right)$ for selected values of system parameters. It is observed that the effect of correlation on the SSC diversity is higher than the SC diversity scheme. Hence, it can be concluded that SC outperforms than SSC diversity in enhancing security of correlated cellular networks.

The $Pr\left(C_{smcast}>0\right)$ is shown in Figure 3 as a function of the average SNR of the multicast channel, $\overline{\gamma}_m$, for different values of ρ. This figure describes the effect of channel correlation, ρ, on the $Pr\left(C_{smcast}>0\right)$ for SC diversity scheme for selected values of system parameters. It is seen that the $Pr\left(C_{smcast}>0\right)$

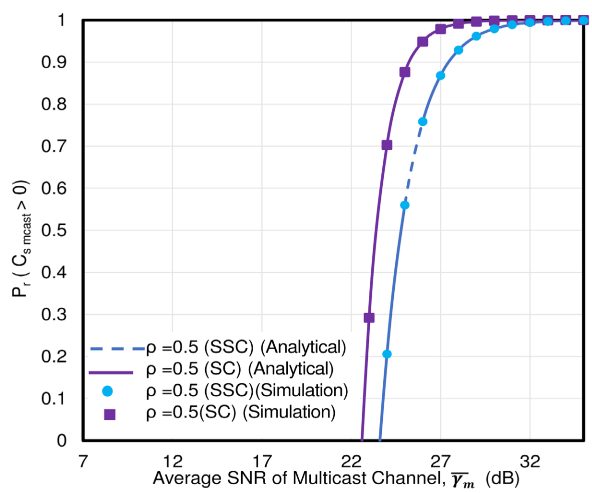

Figure 2. Comparison between SC and SSC diversity schemes in terms of the effect of channel correlation, ρ, on the $Pr\left(C_{smcast}>0\right)$ with $M=4$, $N=2$, $n_r=4$, $n_e=4$, $m=2$ and $\overline{\gamma}_e=10$ dB.

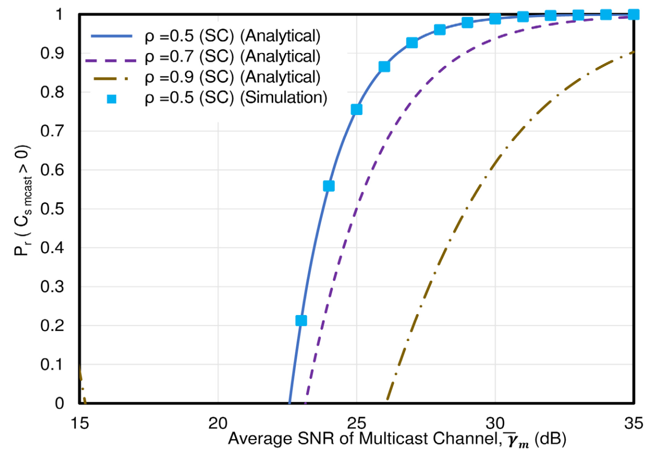

Figure 3. Effect of channel correlation, ρ, on the $Pr\left(C_{smcast} > 0\right)$ for SC diversity scheme with $M = 4$, $N = 2$, $n_r = 4$, $n_e = 4$, $m = 2$ and $\overline{\gamma}_e = 10\text{ dB}$.

decreases if the values of ρ increases from 0.5 (indicated by the solid line) to 0.9 (indicated by the dash-dot line). This is because, the increase in correlation coefficient decreases the antenna diversity gain of multicast users which in turn causes the reduction in secrecy multicast capacity.

Figure 4 describes the effect of channel correlation, ρ, on the $Pr\left(C_{smcast} > 0\right)$ for SSC diversity scheme for selected values of system parameters. Similar to the case of SC diversity, $Pr\left(C_{smcast} > 0\right)$ decreases if the values of ρ increases from 0.5 (indicated by the solid line) to 0.9 (indicated by the dash-dot line). But the effect of ρ on the $Pr\left(C_{smcast} > 0\right)$ is higher compared to the case of SC diversity scheme.

The $Pr\left(C_{smcast} > 0\right)$ is shown in Figure 5 as a function of the average SNR of the multicast channel, $\overline{\gamma}_m$, for different values of *M*. This figure illustrates the effects of the number of multicast users, *M*, on the $Pr\left(C_{smcast} > 0\right)$ for SC and SSC diversity schemes for selected values of system parameters. It is observed that, in the case of SC diversity, the $Pr\left(C_{smcast} > 0\right)$ decreases, if the value of *M* increases from 10 (indicated by the dash-dot-dot line) to 20 (indicated by the solid line) keeping the value of $N = 2$. Similarly, in the case of SSC diversity, the $Pr\left(C_{smcast} > 0\right)$ decreases, if the values of *M* increases from 10 (indicated by the dash-dot line) to 20 (indicated by the solid line with square) keeping the value of $N = 2$. It is seen that although $Pr\left(C_{smcast} > 0\right)$ decreases with *M*, but the effect of *M* is higher in the case of SSC diversity compared to the case of SC diversity. This is because, the increasing in *M*, the bandwidth of each user decreases and the SSC diversity scheme enhances this effect compared to the SC diversity.

Figure 6 shows $Pr\left(C_{smcast} > 0\right)$ as a function of the average SNR of the multicast channel, $\overline{\gamma}_m$, for different values of *m* and $\overline{\gamma}_e$. This figure compares the effects of *m* and $\overline{\gamma}_e$ on the $Pr\left(C_{smcast} > 0\right)$ for SC and SSC diversity schemes. The effects of fading parameter *m* and $\overline{\gamma}_e$ on the SC diversity is higher than the SSC diversity scheme. This is because, the SC scheme chooses the highest

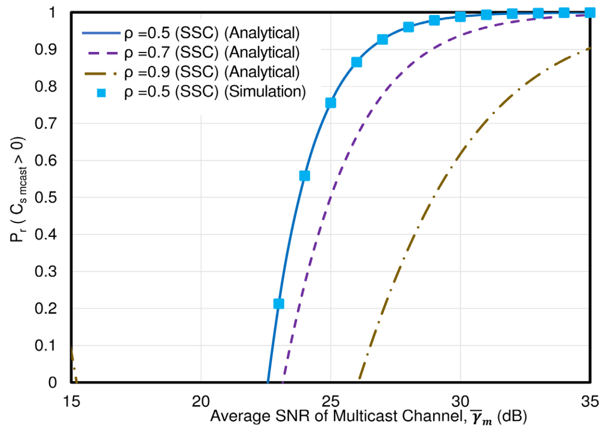

Figure 4. Effect of channel correlation, ρ, on the $Pr(C_{smcast} > 0)$ for SSC diversity scheme with $M = 4$, $N = 2$, $n_r = 4$, $n_e = 4$, $m = 2$ and $\overline{\gamma}_e = 10$ dB.

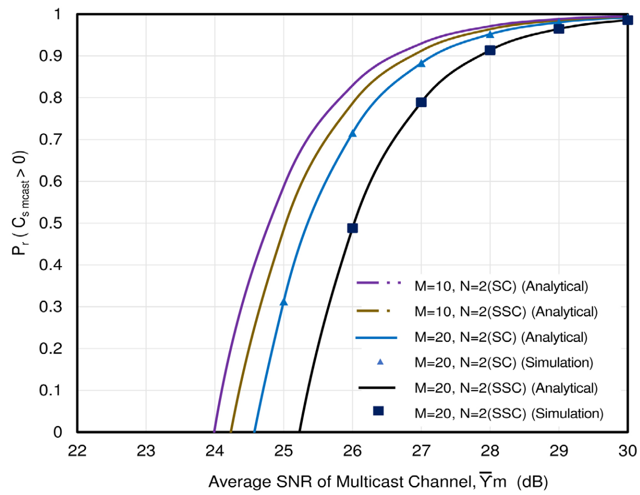

Figure 5. Effect of the number of multicast users, *M*, on the $Pr(C_{smcast} > 0)$ for SC and SSC diversity schemes with $n_r = 4$, $n_e = 4$, $m = 2$, $\rho = 0.5$ and $\overline{\gamma}_e = 10$ dB.

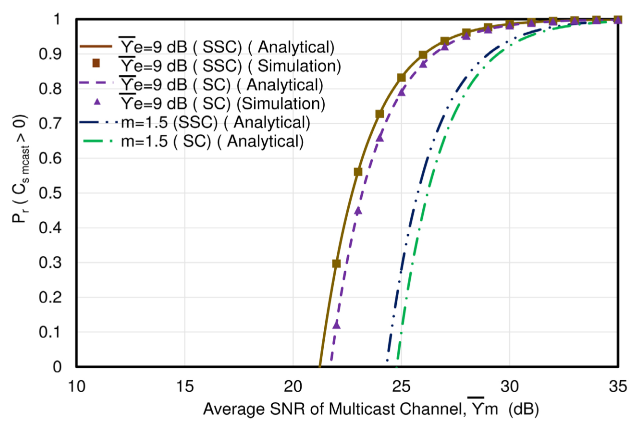

Figure 6. Effect of fading parameter, *m*, and the average SNR of eavesdropper channel, $\overline{\gamma}_e$ on the $Pr(C_{smcast} > 0)$ for SC and SSC diversity schemes with $M = 4$, $N = 2$, $n_r = 4$, $n_e = 4$ and $\rho = 0.5$.

SNR's branch and the SSC diversity scheme selects a particular diversity branch until its SNR drops a predetermined threshold value. In the case of SC diversity, when the value of $\bar{\gamma}_e$ increases the capacity of eavesdropper's channel increases which causes an reduction in the secrecy capacity. On the other hand, the selection of a particular diversity branch cannot ensures the selection of highest SNR branch of eavesdropper channel. The effect of fading causes an reduction in the SNRs of multicast channel and eavesdropper channel. Therefore, the choice of highest SNR branch of eavesdropper channel incorporate lower effect of fading parameter. Moreover, fading is not the enemy of secrecy capacity. Hence, the effects of m and $\bar{\gamma}_e$ on the SC diversity decrease the security significantly compared to the effects of m and $\bar{\gamma}_e$ on the SSC diversity.

The $P_{out}\left(R_{smcast}\right)$ is shown in **Figure 7** as a function of the average SNR of the multicast channel, $\bar{\gamma}_m$, for different values of M and N. This figure describes the effects of M on the SSC diversity and the effects of N on the SC diversity in terms of $P_{out}\left(R_{smcast}\right)$ for selected values of system parameters. It is observed that the $P_{out}\left(R_{smcast}\right)$ increases if the values of M increases from 4 (indicated by the solid line with square) to 8 (indicated by the dash line) keeping the value of $N=4$. $P_{out}\left(R_{smcast}\right)$ also increases if the values of N increases from 4 (indicated by the solid line) to 8 (indicated by the long dash-dot line) keeping the value of $M=4$. Hence, it can be concluded that the security for any kind of diversity scheme decreases due to the effects of both M and N.

The $P_{out}\left(R_{smcast}\right)$ is shown in **Figure 8** as a function of the average SNR of the multicast channel, $\bar{\gamma}_m$, for different values of ρ. This figure describes the effects of ρ on the SC and SSC diversity schemes in terms of $P_{out}\left(R_{smcast}\right)$ for selected values of system parameters. It is seen that in both the cases of SC and SSC diversity schemes, the $P_{out}\left(R_{smcast}\right)$ increases if the values of ρ increases from 0.5 (indicated by the dash-dot line for SC and dash dot-dot line for SSC) to 0.9 (indicated by the long dash-dot line for SC and solid line for SSC), which causes an reduction in the security of multicast network.

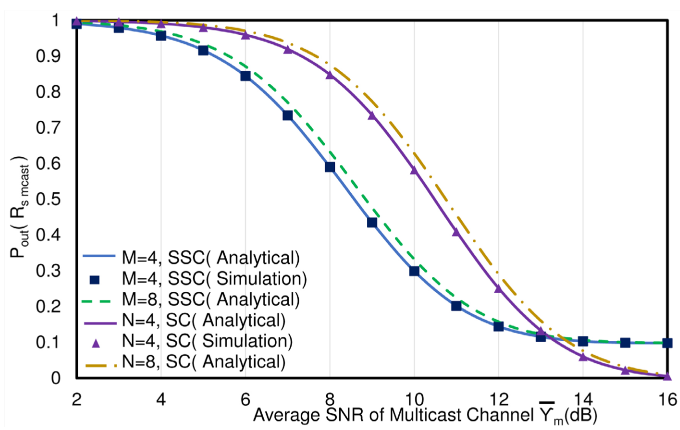

Figure 7. Effect of the number of multicast users, M, and eavesdroppers, N, on the $P_{out}\left(R_{smcast}\right)$ for SSC and SC diversity schemes, respectively, with $n_r=4$, $n_e=8$, $m=1$, $\rho=0.5$ and $\bar{\gamma}_e=10$ dB.

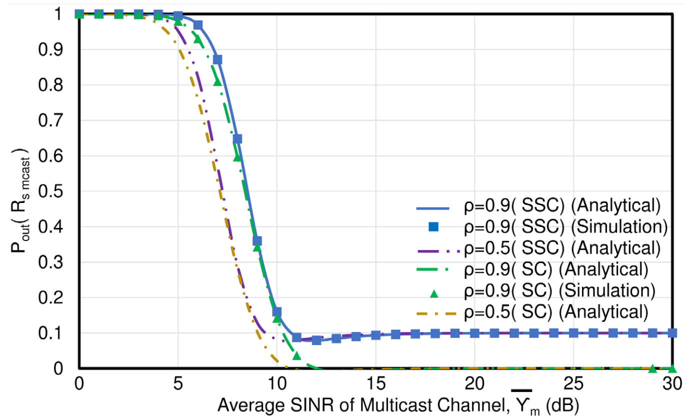

Figure 8. Effect of channel correlation, ρ, on the $P_{out}(R_{smcast})$ for SC and SSC diversity schemes with $M = 2$, $N = 2$, $n_r = 4$, $n_e = 4$, $m = 2$ and $\bar{\gamma}_e = 10$ dB.

Therefore, based on the closed-form analytical expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting, and from the observations of numerical results, the main findings of this paper can be summarized as follows: the security in multicasting degrades with the number of multicast users and eavesdroppers, and due to the antenna correlation. The effect of antenna correlation is more significant in the case of SSC diversity compared to the case of SC diversity. Due to the selection mechanism of SC diversity, it is more sensitive to the change of SNR of eavesdropper's channel compared to the case of SSC diversity scheme.

7. Conclusion

This paper focuses on the comparison of SC and SSC diversity schemes in enhancing the security of correlated cellular network and mitigating the effects of antenna correlation. To achieve this goal, an analytical model has been developed consisting of the closed-form analytical expressions for the probability of non-zero secrecy multicast capacity and the secure outage probability for multicasting considering the effects of antenna correlation. The developed analytical model is verified via Monte-Carlo simulation. The matching between the analytical and simulation results justifies the validity of the developed analytical model. Based on the analytical model and the observation of the numerical results, it can be concluded that the antenna correlation degrades the security of the cellular network in both the cases of SC and SSC diversity schemes, but the effect of this correlation is more significant in the case of SSC diversity compared with the case of SC diversity. In general, diversity schemes reduce the effect of correlation, but this result paves the way for selecting an efficient diversity scheme to mitigate the effect of correlation efficiently.

Conflicts of Interest

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

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