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Outage and throughput performance of cognitive radio based power domain based multiple access

Dinh-Thuan Do, Chi-Bao Le
Faculty of Electronics Technology, Industrial University of Ho Chi Minh City (IUH), Vietnam

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ABSTRACT

This paper considers power domain based multiple access (PDMA) in cognitive radio network to serve numerous users who intend to multiple access to core network. In particular, we investigate the effect of signal combination scheme equipped at PDMA end-users as existence of direct link and relay link. This system model using relay scheme provides performance improvement on the outage probability of two PDMA end-users. We first propose a simple scheme of fixed power allocation to PDMA users who exhibit performance gap and fairness. Inspired by PDMA strategy, we then find signal to noise ratio (SNR) to detect separated signal for each user. In addition, the exact expressions of outage probability are derived in assumption that receiver can cancel out the interference completely with successive interference cancellation (SIC). By exploiting theoretical and simulation results, both considered combination schemes (Maximal Ratio Combining (MRC) and Selection Combining (SC) can achieve improved performance of two PDMA users significantly.

Corresponding Author:

Dinh-Thuan Do,
Faculty of Electronics Technology,
Industrial University of Ho Chi Minh City (IUH),
Ho Chi Minh City, Vietnam.
Email: dodinhthuan@iuh.edu.vn

1. INTRODUCTION

Recently, cognitive radio (CR) has been attracted considerable attention due to its ability to improved spectrum utilization [1]. Achieving advantage of CR to the fifth generation (5G) mobile networks, the primary network containing base station (BS) and BS-served mobile users and the secondary network including two kinds of users (mobile users non-served by the BS) can occupy resource in a same licensed band [2]. Unfortunately, the primary users are under impact of interference from the secondary users located in such a underlay approach. Therefore, it is required to limit the interference to below a certain level to guarantee system performance [3]. In overlay CR, the channels can be selected dynamically without inter-user interference while channel is decided under certain interference constraint in underlay CR. The other is an attractive solution, power domain based multiple access (PDMA), and it is proposed for 5G wireless communications. In PDMA, multiple users are permitted to transmit superimposed signals by employing the same carrier and the same time slot. In real practice, secure issue is challenge in above technologies to enhance spectral efficiency related to spectrum sharing [4]. Although secondary user (SU) can access to a spectrum of a primary user (PU), such SU in cognitive radio networks (CRNs) may meet wiretap legitimate signals due to without appropriate spectrum management policies. Accordingly, secure transmission quality of primary systems in cognitive radio networks (CRNs) using several models have been investigated [5–7]. Fortunately, relaying network provides extended coverage with reasonable outage performance [8-13]. Such relay scheme is proposed to combine with PDMA technology to introduce cooperative PDMA [14, 15]. It is proposed to guarantee the transmit quality of massive users with poor channel [16] and allow more users to access into one spectrum resource block at the same time.

With regard to higher spectrum efficiency, new trend of PDMA and CR is introduced as CR-inspired PDMA as in [17]. The authors studied different receiving qualities of two PDMA systems in two schemes, such as fixed power allocation PDMA and CR-inspired PDMA. To guarantee the channel quality of a user who meets a poor channel condition, the CR-inspired PDMA is recommended [17]. To evaluate system performance, the CR-inspired PDMA indicated better fairness in term of spectrum allocation compared with the fixed-power-allocation PDMA. In other work, the power allocation scheme is developed for two secondary user (SUs) existing in the PDMA-enabled underlay CR (CR PDMA). Such CR PDMA is deploy to enhance the spectral efficiency by using interference cancellation [18]. Thus, to greatly improve the spectrum utilization, PDMA is proposed to integrate into underlay CR with power constraints.

Motivated by [19-25] this paper analyzes the outage and throughput performance by applying the PDMA protocol in a CR network. In this situation, we considers system performance in a downlink communication scenario. The network is composed of a pair of PDMA users, a primary network containing base station (BS) and user while the source in secondary network need a helping relay to forward signal to far user. We assume that all end-users operate in the PDMA transmission protocol at the same time. The main contributions are summarized as follows.

- We propose a new underlay CR PDMA-enabled transmission and provide performance gap of two PDMA users to satisfy the quality of service (QoS) requirements of such CR PDMA system.
- We formulate exact outage probability for two PDMA users while satisfying a given fixed power allocation factors. Then, we confirm outage performance and corresponding throughput in numerical results.
- We analyze the overall network performance, study the problem of fixed power allocation under the constraint of the system total power, and indicate numerical method to solve the optimal problem of throughput performance.

The rest of the paper is organized as follows. Section II presents a PDMA-enabled CR system with a pair of PDMA end-users are served by both sources in primary network and secondary network, secondary source using one relay to serve far PDMA user. In Section III, we extend our study to a situation with fixed power allocation to derive outage probability and corresponding throughput of overall system. Simulation results are shown in Section IV, and conclusions are presented in Section V.

2. SYSTEM MODEL AND CALCULATIONS OF SNR

In this article, we consider a communication with CR PDMA model as shown in Figure 1. This model consists primary network containing a base station (BS) and far PDMA user, a secondary network containing source, relay R and far PDMA user. All entities in the network are equipped with single antenna and the communication of primary and secondary system operates in using the PDMA transmission principles. Assuming that both the relay and two PDMA users can estimate the secondary and primary channels by some learning processes in the actual situation, they can be aware of the channel state information (CSI) of all the channels perfectly. In addition, all channels are assumed to be quasi-static Rayleigh fading, where the channel coefficients are constant for each transmission block but vary independently between different blocks.

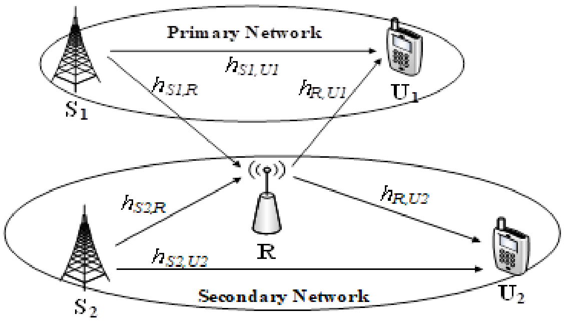

Figure 1. System model of joint CR and PDMA

For the operation of helping relay in secondary systems, relay may receive the synthetic message from the primary source S$_1$ and signal from the secondary source S$_2$. We denote noise terms $\sigma^2=\sigma_R^2=\sigma_{R,U1}^2=\sigma_{R,U2}^2=\sigma_{S1,U1}^2=\sigma_{S2,U2}^2$ and $\rho=\frac{P_{S1}}{\sigma^2}=\frac{P_{S2}}{\sigma^2}=\frac{P_R}{\sigma^2}$. SNR at relay to detect x$_2$:

$$\gamma_{R,x2}=\frac{\rho\left|h_{S2,R}\right|^2}{\rho\left|h_{S1,R}\right|^2+1}. \tag{1}$$

We compute SNR at relay to detect x$_1$

$$\gamma_{R,x1}=\rho\left|h_{S1,R}\right|^2. \tag{2}$$

It can be found SNR at U1 to detect x$_2$

$$\gamma_{RU1,x2}=\frac{a_2\rho\left|h_{R,U1}\right|^2}{a_1\rho\left|h_{R,U1}\right|^2+1}. \tag{3}$$

It need be computed SNR at U1 to detect x$_1$ as

$$\gamma_{RU1,x1}=a_1\rho\left|h_{R,U1}\right|^2. \tag{4}$$

It can be calculated SNR at U2 to detect x$_2$ as

$$\gamma_{RU2,x2}=\frac{a_2\rho\left|h_{R,U2}\right|^2}{a_1\rho\left|h_{R,U2}\right|^2+1}. \tag{5}$$

In direct link of primary network in such CR PDMA, SNR at U1 to detect x$_1$ is given by;

$$\gamma_{S1U1,x1}=\rho\left|h_{S1,U1}\right|^2. \tag{6}$$

Also, in direct link of secondary network in such CR PDMA, SNR at U1 to detect x$_2$ is computed by

$$\gamma_{S2U2,x2}=\rho\left|h_{S2,U2}\right|^2. \tag{7}$$

3. OUTAGE PROBABILITY AND THROUGHPUT ANALYSIS

In this section, we investigated the outage behavior for the CR PDMA downlink cooperative network with perfect CSI. To this end, exact expressions for the outage probability is studied first. In order to best throughput and better understand the behavior of the network, a numerical method is applied to show throughput, while fairness among PDMA users satisfied, regime. We use Maximal Ratio Combining (MRC) to further process signal at U1, U2 as existences of direct link and relay link between the BS and PDMA end-users.

3.1. Scheme I: maximal ratio combining (MRC)

At each destination, two links are combined and hence SNR in such MRC case can be expressed at U1, U2 respectively as;

$$\gamma_{U1}^{MRC}=\rho\left|h_{S1,U1}\right|^2+a_1\rho\left|h_{R,U1}\right|^2, \tag{8}$$

and

$$\gamma_{U2}^{MRC} = \rho\left|h_{S2,U2}\right|^2 + \frac{a_2\rho\left|h_{R,U2}\right|^2}{a_1\rho\left|h_{R,U2}\right|^2+1}. \tag{9}$$

we set new variable $\tau = \dfrac{\gamma_2}{\rho\left(a_2-\gamma_2 a_1\right)}$

then, the outage probability at user U1 can be given by;

$$P_{U1} = \underbrace{\Pr\left(\gamma_{U1}^{MRC}<\gamma_1\right)}_{A_1}\underbrace{\Pr\left(\gamma_{R,x1}>\gamma_1\right)}_{A_2}+\underbrace{\Pr\left(\gamma_{R,x1}<\gamma_1,\gamma_{S1U1,x1}<\gamma_1\right)}_{A_3}. \tag{10}$$

proposition 1: the closed-form expression of outage probability at user U1 can be given by

$$P_{U1} = \varphi_{\mathrm{U1}} e^{\frac{-\gamma_1}{d_{S1R}^{-m}\rho}} + \left(1-e^{\frac{-\gamma_1}{d_{S1R}^{-m}\rho}}\right)\left(1-e^{\frac{-\gamma_1}{d_{S1U1}^{-m}\rho}}\right), \tag{11}$$

where $\varphi_{\mathrm{U1}} = 1-e^{\frac{-\gamma_1}{d_{RU1}^{-m}a_1\rho}} - \dfrac{d_{S1U1}^{-m}}{d_{S1U1}^{-m}-d_{RU1}^{-m}a_1} e^{\frac{-\gamma_1}{d_{S1U1}^{-m}\rho}}\left(1-e^{\frac{-\gamma_1}{a_1\rho}\left(\frac{1}{d_{RU1}^{-m}}-\frac{a_1}{d_{S1U1}^{-m}}\right)}\right)$

Proof:

We have following equation

$$\begin{aligned} A_1 &= \Pr\left(\gamma_{U1}^{MRC}<\gamma_1\right) \\ &= \Pr\left(\left|h_{S1,U1}\right|^2 < \frac{\gamma_1}{\rho} - a_1\left|h_{R,U1}\right|^2, \left|h_{R,U1}\right|^2 < \frac{\gamma_1}{a_1\rho}\right). \end{aligned} \tag{12}$$

Then, it can be further expressed as

$$\begin{aligned} A_1 &= \int_0^{\frac{\gamma_1}{a_1\rho}} F_{\left|h_{S1,U1}\right|^2}\left(\frac{\gamma_1}{\rho}-a_1x\right) f_{\left|h_{R,U1}\right|^2}\left(x\right)dx \\ &= 1-e^{-\frac{\gamma_1}{d_{RU1}^{-m}a_1\rho}} - \frac{d_{S1U1}^{-m}}{d_{S1U1}^{-m}-d_{RU1}^{-m}a_1} e^{-\frac{\gamma_1}{d_{S1U1}^{-m}\rho}}\left(1-e^{-\frac{\gamma_1}{a_1\rho}\left(\frac{1}{d_{RU1}^{-m}}-\frac{a_1}{d_{S1U1}^{-m}}\right)}\right). \end{aligned} \tag{13}$$

Then, two remaining component can be obtained as

$$\begin{aligned} A_2 &= \Pr\left(\gamma_{R,x1}>\gamma_1\right) \\ &= e^{\frac{-\gamma_1}{d_{S1R}^{-m}\rho}}, \end{aligned} \tag{14}$$

and

$$\begin{aligned} A_3 &= \Pr\left(\gamma_{R,x1}<\gamma_1,\gamma_{S1U1,x1}<\gamma_1\right) \\ &= \left(1-e^{-\frac{\gamma_1}{d_{S1R}^{-m}\rho}}\right)\left(1-e^{-\frac{\gamma_1}{d_{S1U1}^{-m}\rho}}\right). \end{aligned} \tag{15}$$

This is end of the proof.
Similarly, outage probability at user U2 can be computed by

$$P_{U2} = \underbrace{\Pr\left(\gamma_{U2}^{MRC} < \gamma_2\right)}_{B_1}\underbrace{\Pr\left(\gamma_{R,x2} > \gamma_2\right)}_{B_2} + \underbrace{\Pr\left(\gamma_{R,x2} < \gamma_2, \gamma_{S2U2,x2} < \gamma_2\right)}_{B_3}. \tag{16}$$

Proposition 2: The closed-form expression of outage probability at user U2 can be given by:

$$P_{U2} = \left[1 - e^{-\frac{\tau}{d_{RU2}^{-m}}} - \frac{e^{\xi}}{\Psi_2}\sum_{n=0}^{\infty}\frac{(-1)^n}{n!\left(d_{RU2}^{-m}a_1\rho\right)^n}\Xi_2\right]\frac{d_{S2R}^{-m}}{d_{S2R}^{-m} + \gamma_2 d_{S1R}^{-m}}e^{\frac{-\gamma_2}{d_{S2R}^{-m}\rho}} + 1 - e^{-\frac{\gamma_2}{d_{S2U2}^{-m}\rho}} - \Upsilon, \tag{17}$$

where $\Xi_2 = \frac{(-1)^{2n+1}\Psi_1^{n+1}}{(n+1)!}\left(\mathrm{Ei}(\xi) - \mathrm{Ei}(\Psi_1)\right) + \sum_{k=0}^{n}\frac{e^{\xi}(1 + a_1\rho\tau)^{n+1}\xi^k - e^{\Psi_1}\Psi_1^k}{(n+1)n\ldots(n+1-k)}$, $\Psi_2 = a_1\rho d_{RU2}^{-m}$,

$\xi = \frac{1}{a_1\rho d_{RU2}^{-m}} - \frac{\gamma_2}{\rho d_{S2U2}^{-m}} - \Psi_1$, $\Psi_1 = -\frac{a_2}{a_1\rho d_{S2U2}^{-m}}$ and $\Upsilon = \frac{d_{S2R}^{-m}}{d_{S2R}^{-m} + d_{S1R}^{-m}\gamma_2}\left(e^{-\frac{\gamma_2}{d_{S2R}^{-m}\rho}} - e^{-\gamma_2\left(\frac{1}{d_{S2U2}^{-m}\rho} + \frac{1}{d_{S2R}^{-m}\rho}\right)}\right)$

Proof: see in appendix

3.2. Scheme II: selection combining (SC)

We consider outage performance of each destination by using Selection Combining (SC) as;

$$\begin{aligned} OP_{U1} &= \Pr\left(\gamma_{S1U1,x1} < \gamma_1\right)\left[1 - \Pr\left(\gamma_{R,x1} > \gamma_1, \gamma_{RU1,x1} > \gamma_1\right)\right] \\ &= \Pr\left(\left|h_{S1,U1}\right|^2 < \frac{\gamma_1}{\rho}\right)\left[1 - \Pr\left(\left|h_{S1,R}\right|^2 > \frac{\gamma_1}{\rho}, \left|h_{R,U1}\right|^2 > \frac{\gamma_1}{a_1\rho}\right)\right]. \end{aligned} \tag{18}$$

Then, it is rewritten as;

$$\begin{aligned} OP_{U1} &= \int_0^{\frac{\gamma_1}{\rho}} f_{\left|h_{S1,U1}\right|^2}(x)dx\left[1 - \int_{\frac{\gamma_1}{\rho}}^{\infty}\int_{\frac{\gamma_1}{a_1\rho}}^{\infty} f_{\left|h_{S1,R}\right|^2}(x) f_{\left|h_{R,U1}\right|^2}(y)dxdy\right] \\ &= 1 - e^{-\frac{\gamma_1}{d_{S1U1}^{-m}\rho}} - e^{-\frac{\gamma_1}{\rho}\left(\frac{1}{d_{S1R}^{-m}} + \frac{1}{d_{RU1}^{-m}a_1}\right)} + e^{-\frac{\gamma_1}{\rho}\left(\frac{1}{d_{S1R}^{-m}} + \frac{1}{d_{RU1}^{-m}a_1} + \frac{1}{d_{S1U1}^{-m}}\right)}. \end{aligned} \tag{19}$$

Consider signal at the second destination, outage performance of U2 is;

$$\begin{aligned} OP_{U2} &= \Pr\left(\gamma_{S2,U2} < \gamma_2\right)\left[1 - \Pr\left(\gamma_{R,x2} > \gamma_2, \gamma_{RU2,x2} > \gamma_2\right)\right] \\ &= \Pr\left(\left|h_{S2,U2}\right|^2 < \frac{\gamma_2}{\rho}\right)\left[1 - \Pr\left(\left|h_{S2,R}\right|^2 > \frac{\gamma_2}{\rho}\left(\rho\left|h_{S1,R}\right|^2 + 1\right), \left|h_{R,U2}\right|^2 > \frac{\gamma_2}{\rho\left(a_2 - \gamma_2 a_1\right)}\right)\right]. \end{aligned} \tag{20}$$

Next, it can be rewritten as;

$$\begin{aligned} OP_{U2} &= \int_0^{\frac{\gamma_2}{\rho}} f_{\left|h_{S2,U2}\right|^2}(x)dx\left[1 - \int_0^{\infty}\int_{\frac{\gamma_2}{\rho}(\rho x+1)}^{\infty} f_{\left|h_{S1,R}\right|^2}(x) f_{\left|h_{S2,R}\right|^2}(x)dxdy \int_{\frac{\gamma_2}{\rho(a_2 - \gamma_2 a_1)}}^{\infty} f_{\left|h_{R,U2}\right|^2}(z)dz\right] \\ &= 1 - e^{-\frac{\gamma_2}{d_{S2U2}^{-m}\rho}} - \frac{d_{S2R}^{-m}}{d_{S2R}^{-m} + d_{S1R}^{-m}\gamma_2}\left[e^{-\frac{\gamma_2}{\rho}\left(\frac{1}{d_{S2R}^{-m}} + \frac{1}{d_{RU2}^{-m}(a_2 - \gamma_2 a_1)}\right)} - e^{-\frac{\gamma_2}{\rho}\left(\frac{1}{d_{S2R}^{-m}} + \frac{1}{d_{RU2}^{-m}(a_2 - \gamma_2 a_1)} + \frac{1}{d_{S2U2}^{-m}}\right)}\right]. \end{aligned} \tag{21}$$

Then, we further examine optimal throughput in case of fixed data rates are known. Such system throughput can be given by

$$\tau = \left(1 - P_{U1}\right) R_1 + \left(1 - P_{U2}\right) R_2 \tag{22}$$

4. NUMERICAL RESULTS

In this section, our parameters are shown to simulate, i.e. power allocation factors $a_1 = 0.2, a_2 = 0.8$, target rates $R_1 = 2$, $R_2 = 0.5$, distances $d_{S1R} = 1\text{m}$, $d_{S2R} = 1\text{m}$, $d_{RU1} = 2\text{m}$, $d_{RU2} = 4\text{m}$, $d_{S1U1} = d_{S1R} + d_{RU1}$ and $d_{S2U2} = d_{S2R} + d_{RU2}$, path-loss exponent $m = 2$. Figure 2 shows impact of target rates on outage performance. In addition, higher transmit SNR at the source node S1, S2 results in better outage performance. To comparison, outage performance of U1 for scheme I is better than that of scheme II. While performance of U2 is similar for two considered schemes.

Figure 3 illustrates that increasing target rates make our system meet outage event. This figure confirms that higher transmit SNR at source leads to better performance. It can be seen slight performance gap for user U2 as comparing two schemes. It can be found highest throughput at optimal target rate as in Figure 4. This result confirms that optimal throughput can be achieved by numerical method. It can be seen slight performance gap as comparing two schemes.

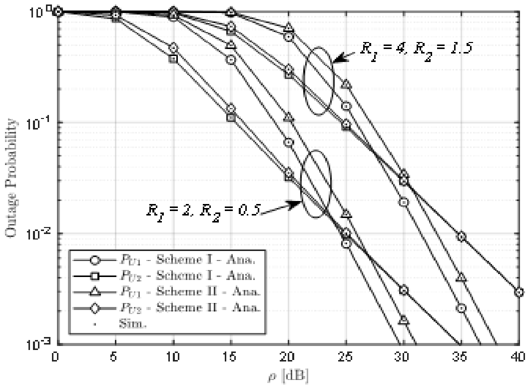

Figure 2. Outage performance versus transmit SNR in CR PDMA

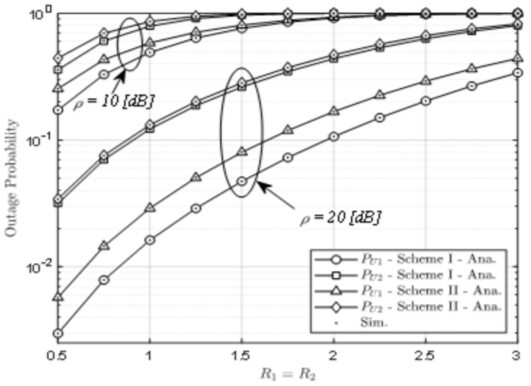

Figure 3. Outage performance versus target rates of CR PDMA

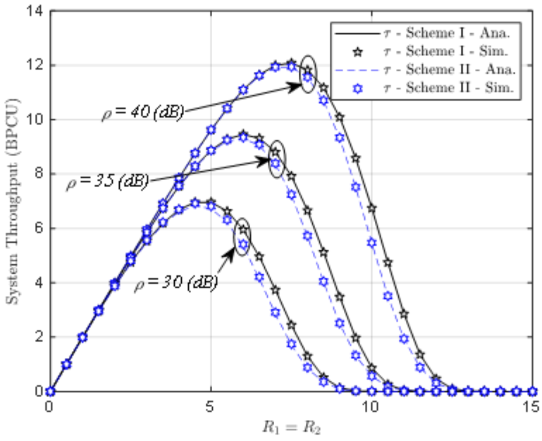

Figure 4. Throughput performance of CR PDMA versus target rates

5. CONCLUSION

In this paper, we studied the fixed power allocation scheme design for robust and guarantee fairness in communication of CR PDMA systems. Each source in each network of CR can serve its own signal forwarding to relay and then the superimposed signal can be received at the PDMA end users. Such model was employed for serving multiple access in downlink. Simulation results revealed that the considered CR PDMA system employing the proposed fixed power allocation scheme can guarantee fairness in PDMA significantly. With respect to specific data rate, it can be achieved highest throughput. Furthermore, our results confirmed the outage small performance gap among two PDMA users of the proposed scheme with respect to varying transmit SNR and revealed the impact of various system parameters on performance.

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APPENDIX

It can be computed each component in such outage of U2 as

$$\begin{aligned} B_1 &= \Pr\left(\left|h_{S2,U2}\right|^2 < \frac{\gamma_2}{\rho} - \frac{a_2\left|h_{R,U2}\right|^2}{a_1\rho\left|h_{R,U2}\right|^2+1}, \left|h_{R,U2}\right|^2 < \tau \right) \\ &= 1 - e^{-\frac{\tau}{d_{RU2}^{-m}}} - \underbrace{\int_0^{\tau} \frac{1}{d_{RU2}^{-m}} e^{-\frac{x}{d_{RU2}^{-m}}} e^{-\frac{1}{d_{S2U2}^{-m}}\left(\frac{\gamma_2}{\rho}-\frac{a_2x}{a_1\rho x+1}\right)} dx}_{\Xi_1} \end{aligned} \tag{A.1}$$

new variable is set as $y = a_1\rho x + 1$ then it can be rewritten as

$$\Xi_1 = \frac{1}{d_{RU2}^{-m}} e^{-\frac{\gamma_2}{\rho d_{S2U2}^{-m}}} \int_1^{\tau a_1\rho+1} e^{-\frac{y-1}{\rho a_1 d_{RU2}^{-m}}} e^{\frac{a_2(y-1)}{\rho d_{S2U2}^{-m} a_1 y}} dy = \frac{e^{\xi}}{\Psi_2} \sum_{n=0}^{\infty} \frac{(-1)^n}{n!\left(d_{RU2}^{-m} a_1\rho\right)^n} \underbrace{\int_1^{\tau a_1\rho+1} y^n e^{-\frac{y}{\rho d_{S2U2}^{-m} a_1 y}} dy}_{\Xi_2} \tag{A.2}$$

where $\xi = \frac{1}{a_1\rho d_{RU2}^{-m}} - \frac{\gamma_2}{\rho d_{S2U2}^{-m}} - \Psi_1$, $\Psi_1 = -\frac{a_2}{a_1\rho d_{S2U2}^{-m}}$ and $\Psi_2 = a_1\rho d_{RU2}^{-m}$. Note that it can be further calculated new equation by using Binomial theorem. We set $z = \frac{1}{y}$ and it can be obtained that

$$\begin{aligned} \Xi_2 &= \int_{\frac{1}{\tau a_1\rho+1}}^{1} \frac{1}{z^{n+2}} e^{-\frac{a_2 z}{\rho d_{S2U2}^{-m} a_1}} dz \\ &= \frac{(-1)^{2n+1}\Psi_1^{n+1}}{(n+1)!}\left(\mathrm{Ei}(\xi)-\mathrm{Ei}(\Psi_1)\right) + \sum_{k=0}^{n} \frac{e^{\xi}(1+a_1\rho\tau)^{n+1}\xi^k - e^{\Psi_1}\Psi_1^k}{(n+1)n\ldots(n+1-k)} \end{aligned} \tag{A.3}$$

where (A.3) can be obtained. Substituting (A.2) and (A.3) into (A.1), is written as

$$B_1 = 1 - e^{-\frac{\tau}{d_{RU2}^{-m}}} - e^{\xi} \sum_{n=0}^{\infty} \frac{(-1)^n}{n!\Psi_2^{n+1}} \left[\frac{(-1)^{2n+1}\Psi_1^{n+1}}{(n+1)!}\left(\mathrm{Ei}(\xi)-\mathrm{Ei}(\Psi_1)\right) + \sum_{k=0}^{n} \frac{e^{\xi}(1+a_1\rho\tau)^{n+1}\xi^k - e^{\Psi_1}\Psi_1^k}{(n+1)n\ldots(n+1-k)} \right] \tag{A.4}$$

Next, it can be obtained

$$\begin{aligned} B_2 &= \Pr\left(\gamma_{R,x2} > \gamma_2\right) \\ &= \int_0^{\infty} \int_{\frac{\gamma_2}{\rho}(\rho x+1)}^{\infty} f_{\left|h_{S1,R}\right|^2}(x) f_{\left|h_{S2,R}\right|^2}(y) dxdy = \frac{d_{S2R}^{-m}}{d_{S2R}^{-m} + \gamma_2 d_{S1R}^{-m}} e^{-\frac{\gamma_2}{d_{S2R}^{-m}\rho}} \end{aligned} \tag{A.5}$$

and

$$\begin{aligned} B_3 &= \left(\left|h_{s2,R}\right|^2 < \frac{\gamma_2}{\rho}\left(\rho\left|h_{S1,R}\right|^2+1\right), \left|h_{s2,U2}\right|^2 < \frac{\gamma_2}{\rho}\right) \\ &= 1 - e^{-\frac{\gamma_2}{d_{S2U2}^{-m}\rho}} - \frac{d_{S2R}^{-m}}{d_{S2R}^{-m} + d_{S1R}^{-m}\gamma_2}\left(e^{\frac{\gamma_2}{d_{S2R}^{-m}\rho}} - e^{-\gamma_2\left(\frac{1}{d_{S2U2}^{-m}\rho}+\frac{1}{d_{S2R}^{-m}\rho}\right)}\right) \end{aligned} \tag{A.6}$$