On Outage Analysis in Overlay CCRN With RF Energy Harvesting and Co-Channel Interference

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On Outage Analysis in Overlay CCRN with RF Energy Harvesting and Co-channel Interference

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Abstract This paper explores the impact of co-channel interference (CCI) on the link outage and radio frequency (RF) energy harvesting (EH). For analysis, co-operative cognitive radio network (CCRN) architecture is considered as system model that supports one-way primary user (PU) and two-way secondary user (SU) communications, using an overlay mode of spectrum sharing. Closed form outage expressions are derived for both PU and SU network in presence of multiple antennas at PUs and CCI at SUs. The effect of CCI on the system performance is studied with respect to interference-to-noise-ratio (INR), transmission power, number of antennas and number of CCI sources. Performance gains are found to achieve $\sim 20\%$ and $\sim 15\%$ for PU and SU outage in two antenna system over a single antenna one.

Keywords SWIPT, spectrum-sharing, co-channel interference, cooperative cognitive radio network.

1 Introduction

Despite the tremendous advancements over the last few decades, wireless networks still face various challenges that include spectrum scarcity, coverage area, reliability in data transmission, co-channel interference (CCI), sustainable network operation etc. Co-operative cognitive radio networks (CCRN) [1] have been emerging as a prominent network architecture for addressing some of the above challenges particularly spectrum scarcity

and sustainable network operation, leveraging the advancements in simultaneous wireless information and power transfer (SWIPT) [2] and cognitive radio enabled spectrum sharing communication [3]. Two-way relay based overlay mode of CCRN can be designed that provides two simultaneous communication sessions through the sharing of primary user (PU) spectrum by secondary users (SUs). The model shows potential applications in internet-of-things (IoT) driven by device-to-device (D2D) based massive machine-type communications (mMTC) over cellular spectrum [4]. It is seen that CCI has a dual impact on SWIPT enabled relaying. It appears in the form of interference, leading to a limitation on the data transmission rate of the relay. At the same time, being a radio frequency (RF) signal, can purposely be used as a source of energy harvesting (EH) and thereby provides relaying power. In the recent literature, decode-and-forward (DF) relay assisted network performance is studied for RF-EH enabled one-way unlicensed SU communication by considering both potential and adverse effect of interference [5]-[7]. In [5], the SU outage probability and ergodic capacity are studied together for both delay-limited and delay-tolerant transmission modes using an underlay mode of CCRN. The dual effect of CCI is also investigated in [6] to analyse the performance of IoT communication over cellular networks using power splitting (PS) and time switching (TS) protocols. In [7], the authors consider the impact of CCI on SWIPT enabled communication using overlay mode of spectrum sharing. Three separate phases are considered in [7] for one-way PU communication and one-way SU communication purpose.

To the best of our knowledge, none of the aforementioned studies have investigated the scope of SWIPT enabled two-way reliable SU communication. Further, multi-antenna transmission, which is a key feature of

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modern cellular communication (i.e, LTE, 5G) has not also been explored in above studies. Besides, the usage of dedicated time slot for EH is found to be inefficient technique [8]. Instead, transmission of energy and information at same phase using hybrid power-time switching relaying (HPTSR) protocol [9] is beneficial to achieve high throughput. In addition, for effective RF-EH, Nakagami fading model is encouraged in the literature [10]. Motivated by all these facts together, the present work investigates the impact of CCI on the reliability of a multi-antenna, spectrum sharing communication over Nakagami fading channel in a SWIPT enabled CCRN framework. We consider HPTSR protocol for SWIPT operation. Moreover, unlike [7], a more realistic system architecture with compact frame structure is adopted in this study to achieve better reliability for one-way PU and two-way SU communications with RF-EH.

2 System Model and Protocol Description

Fig. 1 shows a CCRN system that enables one-way communication between PU nodes (PU_T and PU_R) and two-way communications between pair of SU nodes (SU_1 and SU_2). Due to some obstacles between PU nodes (absence of line-of-sight), PU_T needs some relaying help, nearby SU nodes may forward this data transmission towards PU_R . In return, SU can access the licensed spectrum of PU network for its own data communication. PU_T is assumed to be equipped with multiple antennas while SU nodes and PU_R have single antenna in each. It is also assumed that PU_T node in the network can have scope of availing sufficient energy back-up while the SU nodes are energized only by EH from RF signals using HPTSR protocol. All the links between the pair of nodes follow Nakagami distribution. PU and SU target rate of data transmission are set as $\mathcal{R}_p$ and $\mathcal{R}_s$, respectively.

Let $\mathbf{h}_{1j,n} = [h_{1j,1}, h_{1j,2}, \dots, h_{1j,N_{pa}}]$, h_{2j} and h_s ($j \in 1, 2$) be the channel coefficients between PU_T and SU_j , SU_j and PU_R , SU_1 and SU_2 , respectively, where $\mathbf{h}_{1j,n} \sim \mathcal{CN}(m_k, 1)$ and $h_{2j}, h_s \sim \mathcal{CN}(m_k, 1)$. ζ_{ji} is the channel coefficient between the SU_j and the i^{th} interferer (I_i), with $\zeta_{ji} \sim \mathcal{CN}(m_k, 1)$. Symbol m_k indicates the Nakagami shaping factor and D_{sj1} , D_{sj2} , D_3 and d_{ji} are the distances between PU_T - SU_j , SU_j - PU_R , SU_1 - SU_2 and SU_j - I_i , respectively. $n_{pu} = n_{su} \sim \mathcal{CN}(0, \sigma^2)$ indicate the additive white Gaussian noise (AWGN) at the receiver of PU and SU nodes and σ^2 indicates AWGN variance. Necessary channel state information is assumed to be unavailable at PU nodes.

In the first phase of transmission frame, PU_T sends its signal X_{pt} to both the SU nodes. SU_1 and SU_2 use

Fig. 1 System model and time frame structure

this RF signal for EH and information decoding. Then SU_1 (SU_2) node relays PU_T 's signal to PU_R along with its own information X_{sj} towards SU_p ($j \neq p$; $j, p \in 1, 2$; $p = 2$ for, $l = 2$ and $p = 1$ for, $l = 3$) in the second (third) phase using the energy harvested in the first phase of the transmission frame. The received signal in the first phase at SU_j from PU_T and N_i number of CCIs, can be written as

$$Y_{SU_j} = \sum_{n=1}^{N_{pa}} \sqrt{\frac{P_T}{(D_{sj1})^\nu}} h_{1j,n} X_{pt} + \sum_{i=1}^{N_i} \sqrt{\frac{P_{I_{ji}}}{(d_{ji})^\nu}} \zeta_{ji} X_{I_{ji}} + n_{su} \quad (1)$$

where P_T and $P_{I_{ji}}$ are the transmission power from PU_T to SU_j and I_i to SU_j , respectively. ν indicates the path loss exponent.

Due to very low noise power, it is reasonable that the system associated with RF-EH circuit is unable to harvest the energy from the noise signal. Therefore, the harvested energy at SU_j , using the linear EH model, is expressed as $E_j = \eta \rho_j \left(\frac{\sum_{n=1}^{N_{pa}} P_T |h_{1j,n}|^2}{(D_{sj1})^\nu} + \frac{\sum_{i=1}^{N_i} P_{I_{ji}} |\zeta_{ji}|^2}{(d_{ji})^\nu} \right) \tau T$. ρ_j ($0 < \rho_j < 1$) indicates the PS factor. Harvested power, used by SU_j for broadcasting the information in the l^{th} ($l \in 2, 3$) phase, is determined as $P_{jh}^l = \frac{E_j}{\frac{(1-\tau)T}{2}}$, where $0 < \eta < 1$ indicates RF to DC energy conversion efficiency, $a = \frac{\eta \rho_j P_T}{(D_{sj1})^\nu} \frac{2\tau}{(1-\tau)}$, $b = \frac{\eta \rho_j P_{I_{ji}}}{(d_{ji})^\nu} \frac{2\tau}{(1-\tau)}$.

After EH, the remaining portion $(1 - \rho_j)$ of the received power at SU_j is used to decode the information received during the time interval τT . The achievable rate of the information decoding in the first phase at

SU_j can then be expressed as

$$R_{SU_j}^{(IP)} = \frac{\tau T}{T} \log_2 \left(1 + \frac{\sum_{n=1}^{N_{pa}} \frac{(1-\rho_j)P_T}{(D_{s_{j1}})^{\nu}} |h_{1j,n}|^2}{\frac{\sum_{i=1}^{N_i} (1-\rho_j)P_{I_{ji}} |\zeta_{ji}|^2}{(d_{ji})^{\nu}} + \sigma^2} \right) \quad (2)$$

Here β ($0 < \beta < 1$) fraction of the total harvested power of SU_j is used to forward PU information and the remaining $(1 - \beta)$ fraction of power is allocated to send the signal X_{sj} to SU_p ($j, p \in 1, 2$). Now, the combined signal transmission from SU_j is written as $X_{cs} = \sqrt{\beta P_{jh}^l} X_{pt} + \sqrt{(1 - \beta) P_{jh}^l} X_{sj}$.

The received SINR γ , at PU_R in the l^{th} phase, is written as $\gamma = \frac{a' P_{jh}^l |h_{2j}|^2}{b' P_{jh}^l |h_{2j}|^2 + 1}$ and $a' = \frac{\beta}{(D_{s_{j2}})^{\nu} \sigma^2}$, $b' = \frac{(1-\beta)}{(D_{s_{j2}})^{\nu} \sigma^2}$.

The achievable rate at PU_R in the second phase is expressed as (based on the SINR at PU_R)

$$R_{PU_{Rj}} = \frac{(1-\tau)}{2} \log_2 \{1 + \gamma\} \quad (3)$$

The received signal at SU_p is expressed as

$$Y_{SU_p}^l = \underbrace{\sqrt{\frac{(1-\beta)P_{jh}^l}{D_3^{\nu}}} h_s X_{sj}}_{\text{Desired signal}} + \underbrace{\sqrt{\frac{\beta P_{jh}^l}{D_3^{\nu}}} h_s X_{pt}}_{\text{PU interfering signal}} + \underbrace{\sum_{i=1}^{N_i} \sqrt{\frac{P_{I_{pi}}}{(d_{pi})^{\nu}}} \zeta_{pi} X_{I_{pi}}}_{\text{Interfering signals from interferers}} + \underbrace{n_{su}}_{\text{Noise}} \quad (4)$$

Based on the knowledge of the previous received information from PU signal, SU_p extracts the original information after canceling PU interfering component from the desired signal. Effectively, the achievable rate at SU_p is expressed as

$$R_{SU_{Rp}} = \frac{(1-\tau)}{2} \log_2 \left\{ 1 + \frac{c' P_{jh}^l |h_s|^2}{\sum_{i=1}^{N_i} \frac{d_i' |\zeta_{pi}|^2}{(d_{pi})^{\nu}} + 1} \right\} \quad (5)$$

where $c' = \frac{(1-\beta)}{(D_3)^{\nu} \sigma^2}$, $d_i' = \frac{P_{I_{pi}}}{(d_{pi})^{\nu} \sigma^2}$.

3 Outage Probability Analysis

3.1 PU Outage Probability

Mathematically, PU outage probability is expressed as

$$\mathcal{P}_{out}^{PU} = (1 - \mathcal{P}_{sr_1}) \times (1 - \mathcal{P}_{sr_2}) \quad (6)$$

where $\mathcal{P}_{sr_j} = \frac{\mathcal{P}(R_{SU_j}^{(IP)} \geq \mathcal{R}_p)}{\text{Success of link PU}_T \rightarrow \text{SU}_j} \times \frac{\mathcal{P}(R_{PU_{Rj}} \geq \mathcal{R}_p)}{\text{Success of link SU}_j \rightarrow \text{PU}_R}$.

Using (2), success probability of data transmission from PU_T to SU_j, can be expressed as

$$\mathcal{P}\left\{\frac{A_{pj} X_j}{C_{pj} Z_j + 1} \geq u_{t1}\right\} = \int_{\frac{u_{t1}}{A_{pj}}}^{\infty} f_{x_j}(x_j) dx_j \int_0^{\frac{A_{pj} x_j - u_{t1}}{C_{pj} u_{t1}}} f_{z_j}(z_j) dz_j \quad (7)$$

where $A_{pj} = \frac{(1-\rho_j)P_T}{(D_{s_{j1}})^{\nu} \sigma^2}$, $C_{pj} = \frac{(1-\rho_j)P_{I_{ji}}}{(d_{ji})^{\nu} \sigma^2}$, $u_{t1} = 2^{\left(\frac{\mathcal{R}_p}{\tau}\right)} - 1$. Random variables $X_j = |h_{1j,n}|^2$, $X_3 = |h_{2j}|^2$ and $X_s = |h_s|^2$ follow Nakagami distribution. For mathematical simplicity, the power distribution of all the nearby interferers are considered to be equal. Here, Z_j , V_p are the sum of N_i number of independent identically distributed (i.i.d.) exponential random variables. They follow the central chi-squared distribution given by $Z_j = |\zeta_{ji}|^2$ and $V_p = |\zeta_{pi}|^2$. Probability density function (PDF) of gamma distribution of Z_j is expressed as $f_{Z_j}(z_j) = \frac{N_i^{N_i} z_j^{N_i-1} \exp\left(-\frac{z_j}{N_i}\right)}{\Gamma(N_i)}$.

PDF of X_j is expressed as $f_{X_j}(x_j) = \frac{(N_{pa} m_k)^{N_{pa} m_k} x_j^{N_{pa} m_k - 1} \exp\left(-\frac{x_j}{N_{pa} m_k}\right)}{\Gamma(N_{pa} m_k)}$.

Therefore, (7) can be expressed as [11],

$$\mathcal{P}\left\{\frac{A_{pj} X_j}{C_{pj} Z_j + 1} \geq u_{t1}\right\} = \frac{\Gamma(N_{pa} m_k, N_{pa} m_k \frac{u_{t1}}{A_{pj}})}{\Gamma(N_{pa} m_k)} - \exp\left(-\frac{N_i m_k}{C_{pj} u_{t1}}\right) \frac{M_p(A_{pj})^{p_a - r} (u_{t1})^r \left(\frac{N_i m_k}{C_{pj} u_{t1}}\right)^{p_a} \Gamma\left(m_{rn}, \frac{u_{t1}}{A_{pj}} \left(N_{pa} m_k + \frac{N_i m_k A_{pj}}{C_{pj} u_{t1}}\right)\right)}{\left(N_{pa} m_k + \frac{N_i m_k A_{pj}}{C_{pj} u_{t1}}\right)^{m_{rn}}} \quad (8)$$

where $m_{rn} = N_{pa} m_k + p_a - r$, $\Gamma(\cdot, \cdot)$ and $\gamma(\cdot, \cdot)$ are the upper and the lower incomplete gamma function, respectively, $M_p = \frac{\sum_{p_a=0}^{N_i m_k - 1} (-1)^r \binom{p_a}{r} (N_{pa} m_k)^{N_{pa} m_k}}{p_a! \Gamma(N_{pa} m_k)}$.

Success probability of data transmission over the link SU_j → PU_R is defined as

$$\begin{cases} \mathcal{P}\left[x_3 \geq \frac{u_{tp}}{(a x_j + b z_j)}\right] = I, & \text{for } u_{t2} < \frac{\beta}{(1-\beta)} \\ 0, & \text{otherwise.} \end{cases} \quad (9)$$

Now, $\mathcal{P}\left[x_3 \geq \frac{u_{tp}}{(a x_j + b z_j)}\right]$ can be expressed as (10)

(shown at the top of this page) [11]. Here $u_{t2} = 2^{\left(\frac{2\mathcal{R}_p}{1-\tau}\right)} - 1$, $u_{tp} = \frac{u_{t2}}{(a' - b' u_{t2})}$, $m_x = m_k - p_a + r$. The closed form expression of PU outage can be written as (8)-(10).

3.2 SU Outage Probability

Mathematically, SU outage probability can be expressed as $\mathcal{P}_{out}^{SU} = 1 - [\mathcal{P}(R_{SU_1}^{(IP)} \geq \mathcal{R}_p) \times \mathcal{P}(R_{SU_2}^{(IP)} \geq \mathcal{R}_p) \times \mathcal{P}(R_{SU_{R1}} \geq \mathcal{R}_s) \times \mathcal{P}(R_{SU_{R2}} \geq \mathcal{R}_s)]$.

$$I = \frac{M_p \left[2 \left\{ \frac{u_{tp} N_i}{b} \right\}^{\frac{(m_p)}{2}} K_{m_x} \left\{ 2 m_k \sqrt{\frac{u_{tp} N_i}{b}} \right\} - \frac{2 \sum_{j_t=0}^{N_{pa} m_k + r - 1} \left\{ \frac{u_{tp} N_{pa}}{a} \right\}^{\frac{(m_x - j_t)}{2}} \left\{ u_{tp} m_k \left(N_{pa} - \frac{a N_i}{b} \right) \right\}^{j_t} K_{m_x - j_t} \left\{ 2 m_k \sqrt{\frac{u_{tp} N_{pa}}{a}} \right\}}{j_t! a_t^{j_t}} \right]}{\Gamma(m_k) \left(\frac{1}{m_k} \right)^{m_k} \left(N_{pa} m_k - \frac{a N_i m_k}{b} \right)^{N_{pa} m_k + r}} \times \left(\frac{N_i m_k}{b} \right)^{p_a} (u_{tp})^{p_a - r} (a)^r \Gamma(N_{pa} m_k + r) + \left[\frac{2 \sum_{p_a=0}^{N_{pa} m_k - 1} \left(\frac{u_{tp} N_{pa}}{a} \right)^{\frac{(m_k + p_a)}{2}} (m_k)^{m_k + p_a} K_{m_k - p_a} \left(2 m_k \sqrt{\frac{u_{tp} N_{pa}}{a}} \right)}{p_a! \Gamma(m_k)} \right] \quad (10)$$

Similar to (10), $\mathcal{P} \left[\frac{c'(ax_j + bz_j)x_s}{di'v_p + 1} \geq u_{ts} \right] = I'$ can be written as (11) (shown at the top of the next page) [11]. $u_{ts} = 2 \left(\frac{2\mathcal{R}_s}{1-\tau} \right) - 1$, $m_{sr} = m_k + p_a - r_b + r_g - r_c - r_m$, $K_\rho(\cdot)$ is modified Bessel's function. One can find the closed form expression of SU outage as in (8) and (11).

4 Numerical Results

The necessary simulation parameters are set as follows: noise variance=-90 dBm, $\mathcal{R}_p=1$ bps/Hz, $\mathcal{R}_s=0.2$ bps/Hz, $L_p=70$ m, $d_3=15$ m, $\nu=2.7$, $\eta=0.9$, $\rho_1=\rho_2=\rho=0.9$, $\tau=0.5$. Both SU_1 and SU_2 are placed at the middle position between the two PU nodes. The received power at SU_j from PU_T is 1.5 dBm. An almost 10% value in PU outage probability is achieved at $\beta = 0.94$ for PU transmission power (P_T)=43 dBm.

Figure 2.a illustrates both PU and SU outage performance with respect to the received INR at SU_j . The simulation results match the analytical results. When INR value is small, both PU and SU outage are low. If INR value increases the outage performance of SU deteriorates (increases) rapidly and after a certain value of INR, the outage is found to be 1. The PU outage improves (decreases) very slowly with the increasing value of INR and reaches the minimum value for a specific value of INR. Further enhancement in INR value leads to the deterioration of PU outage. This graphical plot shows the dual impact of CCI. Typical value of 20% and 15% PU and SU outage performance gains are achieved for the increasing value of N_{pa} from 1 to 2 at INR=46 dB. If INR value increases beyond 50 dB, SU outage improvement is insignificant for the increasing value of N_{pa} from 1 to 2.

Figure 2.b.a and 2.c depict performances of both PU and SU outage as the variation on the transmission power of PU_T for different values of both N_i , ρ and for different values of both N_{pa} , N_i , respectively. Performance results are shown for the given value of the received INR = 51 dB. As β is very high, PU outage performance is found to be better (low) than SU outage

as seen in the results. Graphical results also show that performance is improved with the increasing value of N_{pa} . As the interfering signal is another source of RF-EH, the amount of EH is increased with the increasing number of interferers and its impact is also reflected on the system performance. The change of PU outage is insignificant and SU outage is sensitive with the variation of N_i value. Due to this reason, PU outage variation is not shown for the corresponding change in N_i value. Based on the graphical plot, it is found that if the value of ρ is adjusted for a given value of interference power level, then both PU and SU outage gains are achieved. From Figure 2.b it is seen that almost 58% and 18% PU and SU outage performance gains are achieved at $\rho=0.9$ compared to $\rho=0.6$ at $N_i=4$ and $P_T=45$ dBm. For the same average interference power, if the number of antenna changes from $N_i=1$ to 4, then 11% SU outage is found to be deteriorated.

Outage performance is significantly improved with the increasing number of antenna and is highlighted in Figure 2.c. Performance gains of 48% and 10% on PU and SU outage are found with the antenna number $N_{pa}=3$ over $N_{pa}=1$ for $N_i=4$ and $P_T=45$ dBm. Furthermore, PU outage is found to be same and SU outage performance is found to be poor (high) in presence of CCI compared to its absence. The comparative study on SU outage performance between the proposed system with CCI and without CCI is shown in Table I.

Table 1 Comparative study of SU outage performance between presence of CCI and absence of CCI

Outage at transmit power=45 dBm	With CCI	Without CCI
For $\rho_1 = \rho_2 = \rho=0.9$	0.5982 ($N_i=1$), 0.6724 ($N_i=4$)	1.98×10^{-10}
Improvement at $\rho=0.9$ over $\rho=0.6$	18% (for $N_i=1$)	29%
For $N_{pa}=3$	0.65 ($N_i=4$)	1.78×10^{-10}

$$I' = \frac{M_p \left(\frac{N_i m_k}{b} \right)^{p_a} \left(\frac{u_{ts}}{c} \right)^{p_a - r} (a)^r \Gamma_m(d_i')^{t_u - N_i m_k - t_r - r_l} \left(\frac{u_{ts}}{c} \right)^{t_u - T_u} 2 \left(\frac{a}{b} \right)^{t_s - t_a} (-a)^{r_l} \left(\frac{1}{b} \right)^{t_a - t_r - r_l} \left(\frac{u_{ts}}{c} \right)^{t_a - t_r - 2r_l} \left(\frac{N_i m_k}{d_i'} \right)^{r_s - r_j}}{\Gamma(m_k) \Gamma(N_i m_k) (N_i m_k)^{p_a - r - t_k - t_s} (N_{p_a} m_k)^{R_t - r_t} \left(\frac{N_i m_k a c'}{u_{ts} d_i'} \right)^{r_t}}$$

$$(m_k) m_k \left(\frac{N_{p_a} m_k u_{ts}}{a c'} \right)^{r_j} \left\{ \frac{u_{ts} N_{p_a}}{a c'} \right\}^{\frac{T_{ms}}{2}} K_{T_{ms}} \left\{ 2 m_k \sqrt{\frac{u_{ts} N_{p_a}}{a c'}} \right\} + \left[1 - 2 \sum_{p_a=0}^{N_i m_k - 1} \left(\frac{N_i m_k}{d_i'} \right)^{p_a - r_g} \sum_{r_b=0}^{p_a} (-1)^{r_b} \left(\frac{a c'}{u_{ts}} \right)^{p_a - r_b - r_m} \right.$$

$$\left. (d_i')^{r_m} \Gamma(m_{rb}) \left(\frac{u_{ts} N_{p_a} m_k}{a c'} \right)^{r_c - r_g} \sum_{r_c=0}^{m_{rb}-1} \sum_{r_g=0}^{r_c} \left(\frac{r_c}{r_g} \right) \left(\frac{u_{ts} N_{p_a}}{a c'} \right)^{\frac{(m_{rb})}{2}} K_{m_{rb}} \left(2 m_k \sqrt{\frac{u_{ts} N_{p_a}}{a c'}} \right) \right];$$

$$\text{where } \Upsilon_m = \frac{\sum_{t_k=0}^{p_a - r} \binom{p_a - r}{t_k} \sum_{t_u=0}^{T_u} \sum_{t_s=0}^{T_u - 1} \sum_{t_a=0}^{t_s} (-1)^{t_a} \sum_{t_r=0}^{t_a} \sum_{r_l=0}^{t_r} \Gamma(T_u) \binom{t_s}{t_a} \binom{t_a}{r_l} \binom{t_a - t_r}{r_l} \Gamma(R_t) \sum_{r_s=0}^{R_t - 1} \sum_{r_j=0}^{r_s} \binom{r_s}{r_j}}{\binom{T_u}{t_u} t_s! r_s! \sum_{r_t=0}^{R_t} \binom{R_t - r_t}{r_t}}, m_{rb} = N_{p_a} m_k$$

$$+ p_a - r_b, R_t = N_{p_a} m_k + r + t_s - t_a + r_l, T_{ms} = m_k - p_a + r + 2r_l + t_r - t_a - r_j - r_t, T_u = p_a - r - t_k + N_i m_k. \quad (11)$$

Fig. 2 Outage probability vs. (a) received INR at SU_j for $N_i = 1$, (b) transmit power for different values of both N_i and ρ for $N_{p_a} = 2$, (c) transmit power for different values of N_{p_a} and N_i

5 Conclusions

In this paper, the effect of both CCI from multiple interferes and multi-antenna communication on the performance of SWIPT enabled one-way PU and two-way SU communications in overlay mode of CCRN is discussed. Closed form expressions of both PU and SU outages have been obtained that closely match the simulation results. Simulation results show improved outage performance at higher value of PS factor with an increase in number of CCI. It is also observed that with the increase in number of antenna from 1 to 3, PU and SU outage performances are improved by 48% and 10%, respectively.

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