On the Performance of Cognitive Cloud Radio Access Networks in the Presence of Hardware Impairment

Haiyan Huang*, Yangchao Huang†, Zhongdong Wu*, Xinying Li*, and Xuejun Zhang*
*School of Electronic and Information Engineering, Lanzhou Jiaotong University, Lanzhou, 730070, China
†The Information and Navigation College, Air Force Engineering University, Xi'an, 710077, China
Email: huanghaiyan@mail.lzjtu.cn

***Abstract*—In this paper, we explore the cognitive cloud radio access networks with cooperative spectrum sensing in the presence of hardware impairment. Multiuser diversity technique is considered in order to enhance system capacity and improve the reliability of transmission. To avoid interfering with the primary user's communications, the BS intends to transmit messages towards the secondary user only when the spectrum hole is detected. Exact closed form expression for the outage probability of the system understudy is derived over Rayleigh fading channels. It is shown that the hardware impairment degrades the performance of the secondary system. Finally, simulation results are presented to verify the correctness of our analytical derivations.**

I. Introduction

CLOUD radio access networks is considered as a promising technology for the fifth-generation (5G) wireless communication systems to address the bandwidth crunch problem in current cellular systems [1][2]. In cloud radio access network, there are two kinds of users, one is the real-time (RT) user, the other is the delay-tolerant (DT) [3]. Integrating the basic idea of cognitive radio, RT user can be regarded as the primary user (PU), while DT users can be regarded as the secondary users (SUs). The DT user can use the radio channel resources of the RT user to communicate with the BS.

The concept of cognitive radio emerges with the dilemma between spectrum scarcity and underutilization. In cognitive radio networks, the SU is allowed to access the licensed spectrum via overlay, interweave, or underlay mode [4]. In overlay cognitive radio systems, the SU uses sophisticated signal processing and coding to enhance the PUs throughput while obtaining some additional bandwidth for its own communication. In interweave cognitive radio systems, the SU begins to transmit message only when spectrum holes are detected. For spectrum underlay cognitive radio network, the SU can transmit simultaneously with the PU in the same spectrum band as long as the predetermined interference constraints at the primary receiver are satisfied. In order to further make full use of the spectrum source, the spectrum access mode based on spectrum sensing results is proposed, where SU adaptively selects the appropriate access mode according to the final spectrum sensing results [5][6]. In cognitive radio system, multiuser diversity technique is often deployed to enhance the total throughput, and cognitive multiuser network have become one of hot topics in wireless communication [7][8].

On the other hand, in practice, due to a variety of reasons, such as IQ imbalance, amplifier amplitude-amplitude nonlinearities, and phase noise [9][10], the hardware for transmission nodes and reception nodes are imperfect. There have been some works focusing on the impact of hardware impairment in cooperative diversity networks [11]-[14]. However, to the best of the authors' knowledge, the cognitive cloud radio access network with cooperative spectrum sensing in the presence of hardware impairment has not been available in the literature. This paper aims to fill this gap.

In this paper, taking the hardware impairment into account, a framework is developed for the cognitive cloud radio access network with cooperative spectrum sensing in the presence of hardware impairment both at the transmitter and receiver. Exact closed form expression for the outage probability of the system understudy is derived over Rayleigh fading channels, where the cross interference from the PU (RT user) at the SU (DT user) caused by the detection error is considered. It is shown that the hardware impairment degrades the performance of the secondary system. Finally, simulation results are presented to verify the correctness of our analytical derivations. The remainder of this paper is organized as follows. Section II describes the cognitive cloud radio access model with cooperative spectrum sensing in the presence of hardware impairment. In Section III, exact closed-form expressions for the outage probability of the system understudy is provided. Simulation results and discussions are given in Section IV. Finally, Section V concludes this paper.

II. System Model

Consider a downlink C-RAN network, which consists of single real-time (RT) user and N delay-tolerant (DT) users. With the same radio channel resources, M $RRHs$[1] simultaneously serve the RT user, and K $RRHs$[2] cooperatively assist the communication of these N DT users. Based on the basic idea of cognitive radio, the DT user can use the radio channel resources of the RT user to communicate with the BS only when the channel of the RT user is idle. As such, the communication of the under study C-RAN network can be divided into channel detection phase and data transmission phase. For specific time slot, let H_p denote the channel state of the RT user. If the channel of the RT user is vacant, $H_p = H_0$; Otherwise, $H_p = H_1$. The probability of the channel occupied by the RT user is P_a, namely, $P(H_p = H_1) = P_a$ and $P(H_p = H_0) = 1 - P_a$. Moreover, $\hat{H}_{S_n}$ denotes the detection result at the nth DT user S_n. H_c represents the final cooperative detection result.

In the channel detection phase, firstly, N DT users cooperatively detect the RT user's channel and make a decision whether the channel is vacant or not via energy detection independently. If DT users don't detect the RT user, DT users will make a decision '0'; Otherwise, a decision '1' will be made. In energy detection, the received signal is filtered by an ideal bandpass filter with bandwidth W. Then the output of the filter is squared and integrated over a time interval T to produce the test statistic, which is compared with the predetermined detection threshold λ. With $\omega = WT$, the false alarm probability and the detection probability at the nth DT user S_n are respectively given by [6][15]

$$\begin{aligned} P_{S_n\_f} &= P\left(\hat{H}_{S_n} = H_1 \left| H_p = H_0 \right.\right) \\ &= \frac{\Gamma(\omega, \lambda/2)}{\Gamma(WT)} \end{aligned} \tag{1}$$

$$\begin{aligned} P_{S_n\_d} &= P\left(\hat{H}_{S_n} = H_1 \left| H_p = H_1 \right.\right) \\ &= \begin{cases} \Omega \exp\left(-\frac{\lambda}{2}\right) & \omega > 1 \\ \exp\left(-\frac{\lambda}{2\left(1+\Omega_{S_n r_k}\right)}\right) & \omega = 1 \end{cases} \end{aligned} \tag{2}$$

where $\Omega_{S_n r_k}$ denotes the average channel gain between the nth DT user S_n and the kthRRH^1, and Ω is shown as

$$\Omega = \mathrm{Res}\,(g; 0) + \mathrm{Res}\,(g; \Omega_{S_n r_k}/(1 + \Omega_{S_n r_k})) \tag{3}$$

with $\mathrm{Res}\,(g; 0)$ and $\mathrm{Res}\left(g; \frac{\Omega_{S_n r_k}}{1+\Omega_{S_n r_k}}\right)$ denoting the residues of the function $g(z)$ at the origin and at $z = \frac{\Omega_{S_n r_k}}{1+\Omega_{S_n r_k}}$, respectively. $g(z)$ is given by

$$g(z) = \frac{\exp\left(-\frac{\lambda}{2}z\right)}{\left(1 + \Omega_{S_n r_k}\right) z^{(\omega-1)} (1 - \omega) \left(\omega - \frac{\Omega_{S_n r_k}}{1+\Omega_{S_n r_k}}\right)} \tag{4}$$

As we all know, $P_{S_n\_f}$ and $P_{S_n\_d}$ decreases with the growth of the predetermined detection threshold λ. Finally, the management center combines the decision of all DT users by ***OR*** rule. Namely, only when all DT users detect the absence of the RT user, the channel is assumed to be idle. Thus, with decision fusion and ***OR*** rule, the final false alarm probability and detection probability is written as

$$\begin{aligned} P_f &= P\left(H_c = H_1 \left| H_p = H_0 \right.\right) \\ &= 1 - \prod_{n=1}^{N} \left(1 - P_{S_n\_f}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} P_d &= P\left(H_c = H_1 \left| H_p = H_0 \right.\right) \\ &= 1 - \prod_{n=1}^{N} \left(1 - P_{S_n\_d}\right) \end{aligned} \tag{6}$$

Accordingly, $P\left(H_c = H_0 \left| H_p = H_0 \right.\right) = 1 - P_f$ and $P\left(H_c = H_0 \left| H_p = H_1 \right.\right) = 1 - P_d$.

In the data transmission phase, only one best DT user is selected according to the final received SINR to receive the signals from $RRHs^2$. We assume all nodes in the system are equipped with single omni-directional antenna and the transmission power for each RRH is same. The background noise at the receivers are zero mean Gaussian random variables with variance N_0. The channels between any two nodes i and node j are subject to Rayleigh fading. Subsequently, all $RRHs^2$ transmission scheme (ARTS) is described in detail with hardware impairment.

For ARTS, the selected best DT user directly combine the signals from all $RRHs^2$. The signals and channels model are different according to the different channel detection results. In the following, the signals and channels model for the case the RT user does not transmit messages and the DT users sense the absence of the RT user, namely $H_c = H_0, H_p = H_0$, and the case the RT user sends messages but the DT users wrongly sense the absence of the RT user, namely $H_c = H_0$, $H_p = H_1$, are given, respectively.

(1). *Case of* $H_c = H_0, H_p = H_0$: When the RT user does not transmit messages and the DT users sense the absence of the RT user, the received signal at the selected best DT user S_b can be expressed as

$$y_{S_b,\, H_0\_H_0}^{ARTS} = \sum_{k=1}^{K} \sqrt{P_1} h_{R_k S_b} (x + q_k) + \sum_{k=1}^{K} w_{R_k S_b}^{ARTS} + n_{S_b} \tag{7}$$

where x is the transmitted signal from the secondary BS with unit power, P_1 is the transmission power of the kth RRH^2, $h_{R_k S_b}$ is the instantaneous channel fading coefficient between the kth RRH^2 and the selected best DT user S_b, which is subject to complex gaussian distribution with mean 0 and variance $\Omega_{R_k S_b}$, n_{S_b} is the additive white Gaussian noise (AWGN) at the best DT user S_b. In particular, different from the previous work, q_k describes the noises caused by the hardware impairments at the kth RRH^2, which is subject to complex gaussian distribution with mean 0 and variance $\sigma_{R_k}^2$, $w_{R_k S_b}^{ARTS}$ shows the noises generated by the hardware impairments at the best DT user S_b due to the transmission of SU, which is subject to complex gaussian distribution with mean 0 and variance $P_1 \sigma_{R_k S_b}^2 g_{R_k S_b}$ ($g_{R_k S_b} = \left|h_{R_k S_b}\right|^2$). As such, the received SINR at the selected best DT user for the ARTS and the case of $H_c = H_0, H_p = H_0$ is presented as

$$\begin{aligned} \delta_{R_k S_b,\, H_0\_H_0}^{ARTS} &= \frac{\sum\limits_{k=1}^{K} P_1 g_{R_k S_b}}{\sum\limits_{k=1}^{K} P_1 g_{R_k S_b} \left(\sigma_{R_k}^2 + \sigma_{R_k S_b}^2\right) + N_0} \\ &= \frac{\sum\limits_{k=1}^{K} P_1 g_{R_k S_b}}{\sum\limits_{k=1}^{K} P_1 \lambda_{R_k S_b} g_{R_k S_b} + N_0} \end{aligned} \tag{8}$$

where $\lambda_{R_k S_b} = \sigma_{R_k}^2 + \sigma_{R_k S_b}^2$. The DT user with the largest received SINR is selected as the best DT user and receive the signals transmitted from the BS. Mathenatically, for the ARTS and the case of $H_c = H_0, H_p = H_0$, the selected best DT user S_b can be expressed as

$$S_b = \arg \max_{1 \le n \le N} \left(\delta_{R_k S_n,\, H_0\_H_0}^{ARTS} \right) \tag{9}$$

(2). *Case of* $H_c = H_0, H_p = H_1$: When the RT user transmits messages but the DT users sense the absence of the RT user, the received signal at the selected best DT user S_b can be expressed as

$$y_{S_b H_0\_H_1}^{ARTS} = \sum_{k=1}^{K} \sqrt{P_1} h_{R_k S_b} \left(x + q_k \right) + \sum_{k=1}^{K} w_{R_k S_b}^{ARTS} + \sum_{m=1}^{M} \times \sqrt{P_u} h_{r_m S_b} \left(x^p + q_m^p \right) + \sum_{m=1}^{M} w_{r_m S_b} + n_{S_b} \tag{10}$$

where x^p is the transmitted signal from the primary BS with unit power, P_u is the transmission power of the mth RRH^1, $h_{r_m S_b}$ is the instantaneous channel fading coefficient between the mth RRH^1 and the selected best DT user S_b, which is subject to complex gaussian distribution with mean 0 and variance $\Omega_{r_m S_b}$, q_m^p describes the noises caused by the hardware impairments at the mth RRH^1, which is subject to complex gaussian distribution with mean 0 and variance $\sigma_{r_m}^2$, $w_{r_m S_b}$ shows the noises generated by the hardware impairments at the best DT user S_b caused by the transmission of PU, which is subject to complex gaussian distribution with mean 0 and variance $P_u \sigma_{r_m S_b}^2 g_{r_m S_b}$ ($g_{r_m S_b} = |h_{r_m S_b}|^2$). Then, the received SINR at the selected best DT user for the ARTS and the case of $H_c = H_0, H_p = H_1$ is presented as

$$\delta_{R_k S_b H_0\_H_1}^{ARTS} = \frac{\sum\limits_{k=1}^{K} P_1 g_{R_k S_b}}{\sum\limits_{k=1}^{K} P_1 \lambda_{R_k S_b} g_{R_k S_b} + \sum\limits_{m=1}^{M} P_u \varphi_{r_m S_b} g_{r_m S_b} + N_0} \tag{11}$$

where $\varphi_{r_m S_b} = 1 + \sigma_{r_m}^2 + \sigma_{r_m S_b}^2$. The DT user with the largest received SINR is selected as the best DT user and receive the signals transmitted from the BS. Mathenatically, for the ARTS and the case of $H_c = H_0, H_p = H_1$, the selected best DT user S_b can be expressed as

$$S_b = \arg \max_{1 \le n \le N} \left(\delta_{R_k S_n,\, H_0\_H_1}^{ARTS} \right) \tag{12}$$

III. Performance Analysis

In this section, we derive the closed form expression for the exact outage probability of the cognitive cloud radio access networks with cooperative spectrum sensing in the presence of hardware impairment. According to total probability theory, the outage probability for the proposed network is formulated as

$$\begin{aligned} P_{out}^{ARTS} = & P_{outH_0\_H_0}^{ARTS} P\left(H_c = H_0 \left| H_p = H_0 \right. \right) P\left(H_p = H_0 \right) \\ & + P_{outH_0\_H_1}^{ARTS} P\left(H_c = H_0 \left| H_p = H_1 \right. \right) P\left(H_p = H_0 \right) \end{aligned} \tag{13}$$

where $P_{outH_0\_H_0}^{ARTS}$ and $P_{outH_0\_H_1}^{ARTS}$ respectively denote the conditioned outage probability of the cognitive cloud radio access network understudy for the case when the $RRHs^1$ don't transmit messages and cooperative sensing result is right and the case the $RRHs^1$ transmit messages and cooperative sensing result is wrong. According to the sensing results and RT users state, the received SINR at the DT user is different. In the following, we discuss the RT user's outage probability with different sensing results and RT user's state.

A. The $RRHs^1$ don't transmit messages and cooperative sensing result is right

For the case of $H_c = H_0, H_p = H_0$, the RT user does not transmit messages and the DT user senses the spectrum hole. The conditioned outage probability $P_{outH_0\_H_0}^{ARTS}$ can be expressed as

$$P_{outH_0\_H_0}^{ARTS} = \Pr\left(\max_{1 \le n \le N} \left(\delta_{R_k S_b H_0\_H_0}^{ARTS} \right) < \gamma_{th} \right) \tag{14}$$

where γ_{th} (γ_{th}=$2^R - 1$) is the predetermined outage threshold. Combining (8) and using probability theory, (14) can be further written as

$$P_{outH_0\_H_0}^{ARTS} = \prod_{n=1}^{N} \Pr\left(\frac{P_1 X}{P_1 X \lambda_{R_k S_n} + N_0} < \gamma_{th} \right) \tag{15}$$

where $X = \sum\limits_{k=1}^{K} g_{R_k S_n}$. For the convenience of later use, we first give the probability density function (PDF), namely

$$f_X\left(x \right) = \frac{x^{K-1}}{\Gamma\left(K \right) \left(\Omega_{R_k S_n} \right)^K} \exp\left(-\frac{x}{\Omega_{R_k S_n}} \right) \tag{16}$$

Thus, the conditioned outage probability for the single RRH^1 $\Pr\left(\frac{P_1 X}{P_1 X \lambda_{R_k S_n} + N_0} < \gamma_{th} \right)$ can be calculated as

$$\begin{aligned} & \Pr\left(\frac{P_1 X}{P_1 X \lambda_{R_k S_n} + N_0} < \gamma_{th} \right) \\ & = \Pr\left(X \left(1 - \lambda_{R_k S_n} \gamma_{th} \right) < \frac{\gamma_{th} N_0}{P_1} \right) \\ & = \begin{cases} 1 & \lambda_{R_k S_n} > \frac{1}{\gamma_{th}} \\ \int_0^{\frac{\gamma_{th} N_0}{P_1 \left(1 - \lambda_{R_k S_n} \gamma_{th} \right)}} f_X\left(x \right) dx & \lambda_{R_k S_n} < \frac{1}{\gamma_{th}} \end{cases} \end{aligned} \tag{17}$$

By incorporating (16) to (17) and employing some mathematical manipulations, $\Pr\left(\frac{P_1 X}{P_1 X \lambda_{R_k S_n} + N_0} < \gamma_{th} \right)$ can be obtained as

$$\begin{aligned} & \Pr\left(\frac{P_1 X}{P_1 X \lambda_{R_k S_n} + N_0} < \gamma_{th} \right) \\ & = \begin{cases} 1 & \lambda_{R_k S_n} > \frac{1}{\gamma_{th}} \\ \frac{1}{\Gamma(K)} \gamma\left(K, \frac{\gamma_{th} N_0}{P_1 \Omega_{R_k S_n} \left(1 - \lambda_{R_k S_n} \gamma_{th} \right)} \right) & \lambda_{R_k S_n} < \frac{1}{\gamma_{th}} \end{cases} \end{aligned} \tag{18}$$

where $\Gamma(\cdot)$ is the gamma function and $\gamma(\cdot,\cdot)$ is the incomplete gamma functions. Finally, substituting (18) into (15), we can get the exact expressions for the conditioned outage probability of DT user under the case of $H_c = H_0, H_p = H_0$.

B. The $RRHs^1$ transmit messages and cooperative sensing result is wrong

For the case of $H_c = H_0, H_p = H_1$, the RT user transmit messages but the cooperative sensing result shows that there exists a spectrum hole by error. The conditioned outage probability $P^{ARTS}_{outH_0\_H_1}$ can be expressed as

$$\begin{aligned} P^{ARTS}_{outH_0\_H_1} &= \Pr\left(\max_{1\le n\le N}\left(\delta^{ARTS}_{R_kS_bH_0\_H_1}\right) < \gamma_{th}\right) \\ &= \prod_{n=1}^{N} \Pr\left(\frac{P_1 X}{P_1\lambda_{R_kS_n}X + P_u\varphi_{r_mS_n}Y + N_0} < \gamma_{th}\right) \end{aligned} \quad (19)$$

where $Y = \sum_{m=1}^{M} g_{r_mS_n}$ which has a similar PDF as X, and the conditioned outage probability for the single RRH^1 $\Pr\left(\frac{P_1X}{P_1\lambda_{R_kS_n}X+P_u\varphi_{r_mS_n}Y+N_0} < \gamma_{th}\right)$ is given by

$$\begin{aligned} &\Pr\left(\frac{P_1 X}{P_1\lambda_{R_kS_n}X + P_u\varphi_{r_mS_n}Y + N_0} < \gamma_{th}\right) \\ &= \Pr\left(X\left(1-\gamma_{th}\lambda_{R_kS_n}\right) < \frac{\gamma_{th}P_u\varphi_{r_mS_n}Y + \gamma_{th}N_0}{P_1}\right) \\ &= \begin{cases} 1 & \lambda_{R_kS_n} > \frac{1}{\gamma_{th}} \\ J_1 & \lambda_{R_kS_n} < \frac{1}{\gamma_{th}} \end{cases} \end{aligned} \quad (20)$$

where

$$J_1 = \int_0^\infty \int_0^{\frac{\gamma_{th}P_u\varphi_{r_mS_n}y+\gamma_{th}N_0}{P_1\left(1-\lambda_{R_kS_n}\gamma_{th}\right)}} f_X(x)\, f_Y(y)\, dx dy \quad (21)$$

Combining the PDF of X and employing some mathematical manipulations, J_1 can be rewritten as

$$\begin{aligned} J_1 &= \int_0^\infty \int_0^{\frac{\gamma_{th}P_u\varphi_{r_mS_n}y+\gamma_{th}N_0}{P_1\left(1-\lambda_{R_kS_n}\gamma_{th}\right)}} \frac{x^{K-1}}{\Gamma(K)\left(\Omega_{R_kS_n}\right)^K} \\ &\quad \times \exp\left(-\frac{x}{\Omega_{R_kS_n}}\right) f_Y(y)\, dx dy \\ &= \int_0^\infty \gamma\left(K, \frac{\gamma_{th}P_u\varphi_{r_mS_n}y + \gamma_{th}N_0}{P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right)}\right) \frac{f_Y(y)}{\Gamma(K)} dy \end{aligned} \quad (22)$$

It is noted that (22) cannot be obtained directly due to the presence of the incomplete gamma functions. Thus, by using $\gamma(n,x) = (n-1)!\left[1 - e^{-x}\sum_{m=0}^{n-1}\frac{x^m}{m!}\right]$ [16], J_1 can be obtained as

$$\begin{aligned} J_1 = &1 - \exp\left(-\frac{\gamma_{th}N_0}{P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right)}\right) \sum_{l=0}^{K-l}\sum_{l_1=0}^{l} \\ &\times \frac{C_l^{l_1}\left(\gamma_{th}N_0\right)^{l-l_1}\left(\gamma_{th}P_u\varphi_{r_mS_n}\right)^{l_1}}{l!\left[P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right)\right]^l} J_2 \end{aligned} \quad (23)$$

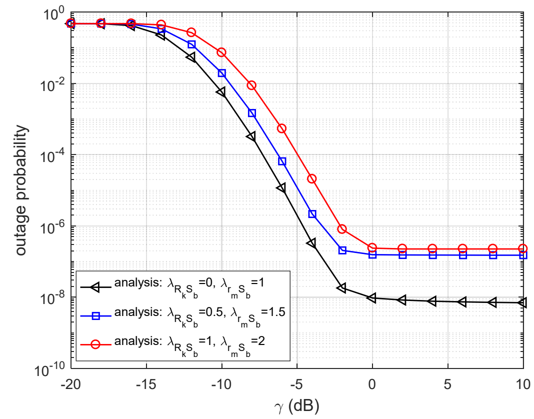

Fig. 1. Outage probability versus γ.

where

$$\begin{aligned} J_2 &= \int_0^\infty y^{l_1}\exp\left(-\frac{\gamma_{th}P_u\varphi_{r_mS_n}y}{P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right)}\right) f_Y(y)\, dy \\ &= \frac{\Gamma(l_1+M)}{\Gamma(M)} \\ &\times \frac{\left(\Omega_{r_kS_n}\right)^{l_1}\left(P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right)\right)^{l_1+M}}{\left(P_1\Omega_{R_kS_n}\left(1-\lambda_{R_kS_n}\gamma_{th}\right) + \gamma_{th}P_u\varphi_{r_mS_n}\Omega_{r_kS_n}\right)^{l_1+M}} \end{aligned} \quad (24)$$

Then incorporating (20), (23), and (24) to (19) yields the exact expressions for the conditioned outage probability of DT user under the case of $H_c = H_0, H_p = H_1$.

IV. Simulation Results

In this section, the application examples are given to confirm our analysis.

Fig. 1 shows the outage probability of the DT user for the cognitive radio network with cooperative spectrum sensing in the presence of hardware impairment against SNR γ (γ=$1/N_0$) with $\Omega_{R_kS_n} = 2$ dB, $\Omega_{r_mS_n} = 2$ dB, $P_1 = 2$ dB, $P_u = 4$ dB, $R = 0.5$ bit/s/Hz, $N = 3$, $K = 3$, and $M = 3$. Obviously, the outage probability decreases as γ grows since the received SINR at the selected best DT user is increased. One can observe that the outage performance with hardware impairment is worse than that with perfect hardware. For example, when $\gamma = 0$ dB, the outage probability of the SU with hardware impairment, namely $\lambda_{R_kS_b} = 1$ and $\lambda_{r_mS_b} = 2$, is 2.38×10^{-7}, while the outage probability of the SU with perfect hardware, namely $\lambda_{R_kS_b} = 0$ and $\lambda_{r_mS_b} = 1$, is 9.47×10^{-9}.

Fig. 2 gives the outage probability of the DT user for the cognitive radio network with cooperative spectrum sensing in the presence of hardware impairment against SNR γ for several number of DT users $N = \{1,2,4\}$ with $\Omega_{R_kS_n} = 2$ dB, $\Omega_{r_mS_n} = 2$ dB, $P_1 = 2$ dB, $P_u = 4$ dB, $R = 0.5$ bit/s/Hz, $\sigma_{R_kS_b} = \sigma_{r_mS_b}$, $K = 3$, and $M = 3$. As can be seen, with the increasing of the number of DT users, the outage performance of the secondary system is improved, which is comprehensible since the multiuser diversity is obtained. For

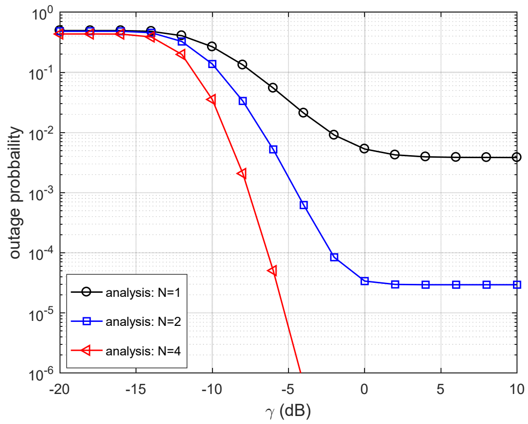

Fig. 2. The outage probability versus γ.

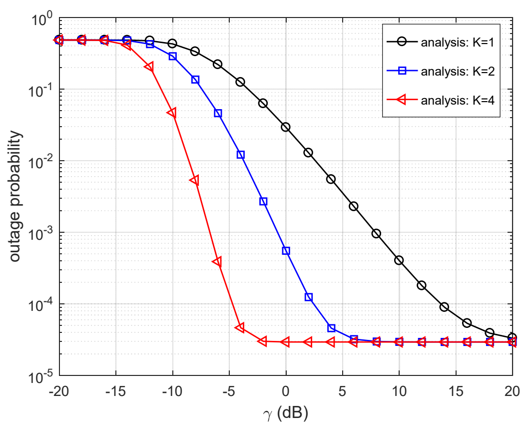

Fig. 3. The outage probability versus P_{max}.

example, when $\gamma = 0$ dB, $N = 1$ results in outage 5.31×10^{-3}, while $N = 2$ results in outage 3.38×10^{-5}. As observed, the outage probability tends to be stable in the high SNR regime, namely, there exist outage floors in the high SNR regime, which is caused by the interference from the RT user when the RT user transmit messages but the cooperative sensing result shows that there exists a spectrum hole by error. However, the outage floor can be decreased by an increase of the number of DT users.

Fig. 3 presents the outage probability of the DT user for the cognitive radio network with cooperative spectrum sensing in the presence of hardware impairment against SNR γ for $K = \{1, 2, 4\}$ with $\Omega_{R_k S_n} = 2$ dB, $\Omega_{r_m S_n} = 2$ dB, $P_1 = 2$ dB, $P_u = 4$ dB, $R = 0.5$ bit/s/Hz, $\sigma_{R_k S_b} = \sigma_{r_m S_b}$, $N = 2$, and $M = 3$. It can be observed that, with an increase of K, the performance for the secondary network improves when SNR is relatively small, while the outage probability for secondary network almost keeps unchanged when SNR is larger.

V. Conclusion

In this paper, the exact closed form expression for the outage probability of the DT user is derived over Rayleigh fading channels for the proposed cognitive cloud radio access network with cooperative in the presence of hardware impairment. Particularly, one best DT user is selected to receive the messages transmitted from the BS. It was seen that the hardware impairment leads to the decrease of the outage performance for the system understudy, and there exist outage floor due to the detection error.

VI. Acknowledgement

This work was supported by the Deepening Research on the Key Technology for Next Generation Mobile Communications of Railway under Grant 2017X013-A, the National Natural Science Foundation of China under Grant 61762058, the Scientifical and Technological Project of Gansu Province under Grant 1610RJZA056, and the Key Laboratory Opening Project of Opto-Technology and Intelligent Control Ministry of Education under Grant KFKT2016-7.

References

[1] F. Liu, P. Shu, H. Jin, L. Ding, J. Yu, D. Niu, and B. Li, "Gearing resource-poor mobile devices with powerful clouds: architectures, challenges, and applications, *IEEE Wireless Communications*, vol. 20, no. 3, pp. 14-22, Jun 2013.

[2] "C-RAN: The Road Towards Green RAN, White Paper 2.5 ed. China Mobile Res. Inst., Beijing, China, 2011.

[3] A. Jalil, S. Cherkaoui, and A. Hafid, "On Channel Reuse for Cloud Network Users, in *Proc. IEEE GLOBEOM*, Dec. 2015, pp. 1-6.

[4] A. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, "Breaking spectrum gridlock with cognitive radios: An information theoretic perspective, *Proceeding of IEEE*, vol. 97, no. 5, pp. 894-914, May. 2009.

[5] Y. Zou, J. Zhu, B. Zheng, and Y. Yao, "An adaptive cooperation diversity scheme with best-relay selection in cognitive radio networks, *IEEE Trans. Wireless Commun.*, vol. 10, no. 2, pp. 648-659, Feb. 2011.

[6] J. Si, H. Huang, Z. Li, B. Hao, and R. Gao, "Performance analysis of adaptive modulation in cognitive relay network with cooperative spectrum sensing, *IEEE Trans. Commun.*, vol. 62, no. 7, pp. 2198-2211, Feb. 2014.

[7] F. R. V. Guimaraes, D. B. da Costa, T. A. Tsiftsis, C. C. Cavalcante, and G. K. Karagiannidis, "Multiuser and multirelay cognitive radio networks under spectrum-sharing constraints," *IEEE Trans. Veh. Technol.*, vol. 63, no. 1, pp. 433-439, 2014.

[8] L. Yang, J. Chen, Y. Kuo, and H. Zhang, "Outage performance of DF-Based cooperative multicast in spectrum-sharing cognitive relay networks," *IEEE Commun. Lett.*, vol. 18, no. 7, pp. 1250-1253, 2014.

[9] E. Costa and S. Pupolin, "m-QAM-OFDM system performance in the presence of a nonlinear amplifier and phase noise," *IEEE Trans. Commun.*, vol. 50, no. 3, pp. 462-472, Mar. 2002.

[10] M. Mokhtar, A.-A. A. Boulogeorgos, G. K. Karagiannidis, and N. Al-Dhahir, "OFDM opportunistic relaying under joint transmit/receive I/Q imbalance," *IEEE Trans. Commun.*, vol. 62, no. 5, pp. 1458-1468, May 2014.

[11] M. Matthaiou, A. Papadogiannis, E. Bjornson, and M. Debbah, "Two-way relaying under the presence of relay transceiver hardware impairments," *IEEE Commun. Lett.*, vol. 17, no. 6, pp. 1136-1139, June 2013.

[12] N. H. Nhat, V. N. Q. Bao, N. L. Trung, and M. Debbah, "Relay selection in two-way relaying networks with the presence of hardware impairment at relay transceiver," in *Proc. International Conference on Advanced Technologies for Communications (ATC)*, Hanoi, Vietnam, Oct. 2014.

[13] E. Bjornson, M. Matthaiou, and M. Debbah, "A new nook at dual-hop relaying: Performance limits with hardware impairments," *IEEE Trans. Commun.*, vol. 61, no. 11, pp. 4512-4525, Nov. 2013.

[14] T. T. Duy, T. Q. Duong, D. B. Costa, V. N. Q. Bao, and M. Elkashlan, "Proactive relay selection with joint impact of hardware impairment and co-channel interference," *IEEE Trans. Commun.*, vol. 63, no. 5, pp. 1594-1606, May. 2015.

[15] F. F. Digham, M. Alouini, and M. K. Simon, "On the energy detection of unknown signals over fading channels, *IEEE Trans. Commun.*, vol. 55, no. 1, pp. 21-24, Jan. 2007.

[16] I. Gradshteyn, I. Ryzhik, and A. Jeffrey, *Table of Integrals, Series, and Products*. Academic Press, 2007.