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# On Cyclic Delay Diversity with Single Carrier OFDM Based Cognitive Radio Networks

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***Abstract:***
*Cyclic Delay Diversity (CDD) is a diversity scheme used in OFDM-based telecommunication systems, transforming spatial diversity into frequency diversity and thus avoiding intersymbol interference without entailing the receiver to be aware of the transmission strategy making the signal more reliable achieving full diversity gain in cooperative systems. Here the analyzation of the influence of CDD-SC scheme in Cognitive Radio Network (CRN) is done with the challenge of overcoming the complication called channel estimation along with overhead in CNR. More specifically, the closed-form expressions for outage probability and symbol error rate are divided under different frequencies among independent and identically distributed (i.i.d.) frequency selective fading channel model i.e., the signal is divided into different frequencies and transmitted among several narrow band channels of different characteristics. It is useful in the reduction of interference and crosstalk. The results reveal the diversity order of the proposed system to be mainly affected by the number of multipath components that are available in the CNR.*

***Keywords:*** *Cognitive Radio Network, Cyclic Delay Diversity, Single Carrier*

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## I. Introduction

CDD (cyclic delay diversity): CDD is a kind of transmit diversity mechanism implemented by applying a different phase delay (cyclic phase delay) for each OFDM subcarrier. It is used in spatial multiplexing to increase diversity between the 2 spatial paths. Simply in CDD, one antenna is transmitting the original copy of data and the other antenna is transmitting the cyclic shifted version of the original data. The cyclic shift in time domain produce the phase shift for each symbol in frequency domain and it generate the same effect as frequency diversity. CDD is an improved variant of delay diversity scheme suitable for cyclic prefixed block transmission systems such as orthogonal frequency division multiplexing (OFDM) [1,2].The basic idea behind CDD scheme is that, the transmitted signal is first cyclically shifted by applying different cyclic shifts on it so as to create rich multipath components and later, the cyclic prefix (CP) is added to the transmitted symbol block so as to mitigate the inter symbol interference. CDD, is simple to deploy since it does not need additional complexity at both the transmitter and receiver [4]. Orthogonal Frequency Division Multiplexing, so called OFDM, has found a prominent place in various wireless systems and networks as a method of encoding data over multiple carrier frequencies. OFDM-based communication systems, however, lacking inherent diversity, are capable of benefiting from different spatial diversity schemes. One such scheme, CDD is a method to provide spatial diversity which can be also interpreted as a Space-Time Block Coding (STBC) step. CDD is standard compatible compared with other transmit diversity schemes. Furthermore, unlike STBC scheme that suffers rate loss when the number of transmit antennas $N_t$ is more than 2, CDD can be used without rate reduction. Because of the provided diversity and flexible deployment with various antenna configurations, it has been used to enhance reception performance and extend cellular coverage in various wireless systems [3-7].Subsequently, we briefly introduce the application of cyclic delay diversity (CDD) to OFDM systems as described in detail in. In it is shown that CDD can be viewed as space-time block coding method. In present scenario for future mobile radio systems are expected to provide and serve a wide range of applications, which inherently enforces high data rates. Currently, data rates of up to 100 Mbps and a bandwidth allocation of about 100 MHz are under discussion for mobile communication systems of the 4th generation. Multicarrier (MC) based systems, are approved candidates for providing the demanded data rates in a wide range of multipath fading environments with reasonable complexity. For further increase of the capacity and performance of such communication systems, multiple antenna (MIMO) techniques at both receiver and transmitter can be applied.Diversity is the technique to improve link performance and/or increase data throughput by manipulating the statistical characteristics of the wireless link. There are different forms of diversity that are traditionally exploited in communications systems, such as temporal diversity in time-selective fading channels, spectral diversity in frequency-selective fading channels and spatial diversity in cases where the channel is neither time-selective nor frequency selective (i.e. when system constraints preclude the use of temporal or spectral forms of diversity, spatial diversity can be used to provide substantial improvement in system performance). For example, Interleaving makes use of temporal diversity; and spread spectrum communications and OFDM exploits spectral diversity. Spatial diversity involves using of multiple antennas in transmitter and/or receiver. In a broad sense, the antenna diversity or spatial diversity can be classified in two categories: transmit diversity and receive diversity.

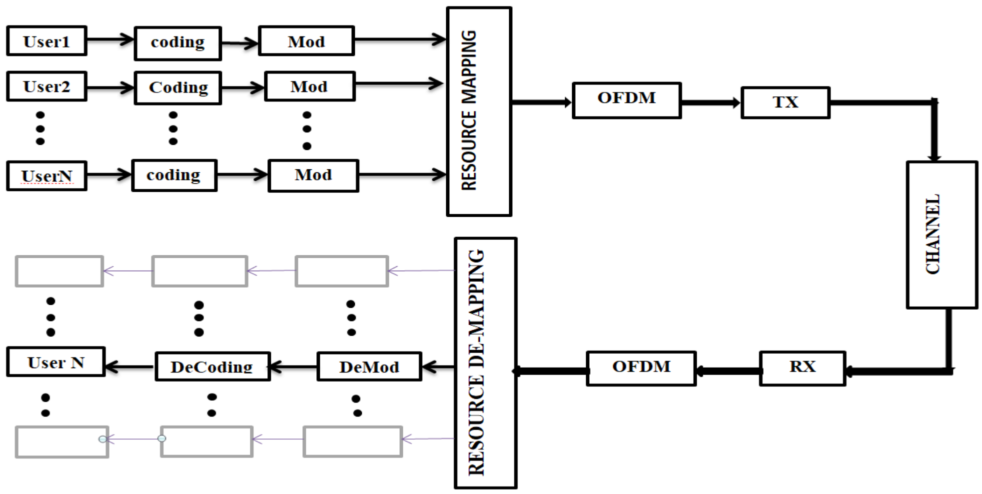


***Fig.1.1:*** *Generic OFDM system representation*

To avoid multipath overlapping and achieve maximum diversity in CDD systems, the cyclic delay differences should be larger than the individual maximum channel length. Consequently, zero gaps between individual impulse responses together with the random silent intervals between nonzero taps render the extremely long equivalent channel sparse. Previous studies on sparse channel estimation indicate that presetting the channel estimator to maximum channel length is inefficient and the performance can be improved when the nonzero taps are accurately detected and estimated. Different from these approaches, we use the mixed norm optimization originally developed for sparse reconstruction to enhance the estimation performance.

## II. System &Channel Estimation Model

The fact that Cyclic Delay Diversity (CDD) based Single Carrier (SC) scheme increases the frequency diversity without entailing the receiver to be aware of the transmission strategy, makes it to be a good candidate for achieving full diversity gain in cooperative systems. In this paper, we scrutinize the impact of CDD-SC scheme in Cognitive Radio Network (CRN) with a great aim of overcoming the channel estimation challenge as well as the signaling overhead in CRN. In a multiuser communication environment, all users must follow a set of rules to access the wireless channel in order to share the common resources efficiently. Many conventional wireless systems are based on the cellular concept, where the covered area is divided into geographical cells. Mobile stations in each cell communicate with the corresponding BS or access point. The communication channel is referred to as downlink when the BS is transmitting messages to the mobile stations. In contrast, when mobile stations are transmitting to the BS, the channel is referred to as uplink. Besides the downlink or uplink systems which constitute a centralized or infrastructure network topology, ad hoc networks form a distributed network topology. In distributed networks, any node can communicate with any node.

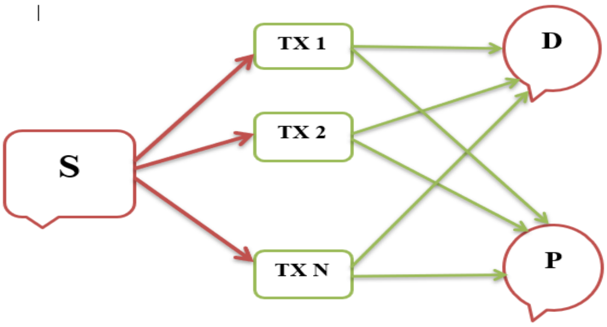


***Fig.2.1:*** *System model. Where all $TX_N$ communicate with S via perfect backhaul links $\{b_t\}_{t=1}^{N}$ and with both D and P via channel co-effecients $\{h_t^d\}_{t=1}^{N}$ , $\{h_t^p\}_{t=1}^{N}$ respectively*

The block diagram of the considered CDD spectrum sharing system is shown in Fig. 2. The source node or control unit denoted by (S) communicates with N CDD transmitters ($TX_N$) via a perfect backhaul$\{b_t\}_{t=1}^{N}$. The secondary user network comprising of S, N CDD ($TX_N$)[1] and the secondary receiver (D) shares the spectrum with the licensed band of the primary user (P) on condition that D's transmitted signal doesn't exceed the peak interference threshold of P. Assuming that the remaining channels undergo i.i.d. frequency selective fading and all nodes are equipped with a single antenna. An advancement is taken further to explore the CDD-SCCP scheme performance in Cognitive Radio Networks (CRN), i.e., CRN allows the sharing of the spectrum between the secondary user and the primary user as long as the secondary receiver's transmit power is constrained under a given threshold value which the primary user can tolerate. Until now, almost all published works on CRN suggested diverse schemes that put into consideration CSI which is of course challenging to attain and at the same time increases the signaling overhead effect on the network. Aiming at achieving maximum diversity gain in CRN with no CSI requirement, later performance analyzation of CDD-SCCP in CRN is done.

- Transmitted power at $T_{XN}$ is limited by the maximum allowable power and maximum tolerable interference power of the primary user (ψ).

$$\hat{p}_t = min\left(p_{max}\ , \frac{\varphi}{\left|h_t^p\right|^2}\right) \quad \text{-------------------- (1)}$$

- The signal-to-noise ratio (SNR) over transmitter to receiver is written as

$$\gamma_t^d = \hat{p}_t . \left|h_t^d\right|^2 \quad \text{--------------------(2)}$$

- During transmission, CDD cyclically shifts the transmit symbol t so as to create rich multipath components and after it prepends a CP in order to avert the Inter Symbol Interference (ISI).
- The right circular matrix has the reception as

$$y_t^d = \sum_{t=1}^{N} \sqrt{\hat{p}_t\, H_t^d}\ t + \eta_d \quad \text{--------------------(3)}$$

- The CDF and the PDF of the random variable (RV) are given by

$$F_\gamma(y) = 1 - e^{-\frac{y}{\hat{p}_t}} \sum_{j=0}^{w_t-1} \frac{1}{j!}\left(\frac{y}{\hat{p}_t}\right)^j$$

$$f_{\gamma(y)=}\frac{1}{\Gamma(w_t)(\hat{p}_t)^{w_t}} y^{w_t-1} e^{-\frac{y}{\hat{p}_t}} \quad \text{--------------------(4)}$$

- Assuming i.i.d. frequency selective fading channel which means that each channel possesses the same number of multipath components, the analysis of distributed CDD $TX_N$ with largest SNR will require the mathematical tool such as statistical order [22].
- Assume $\gamma_1^d \ldots \gamma_n^d$ be i.i.d. variable from a population $F_\gamma(y)$.
- Let $\gamma_{1:n}^d < \ldots < \gamma_{n:n}^d$ be statistical order in increasing mode, such that the distribution function of $\gamma_{t:n}^d$ $(1 \leq t \leq n)$I expressed as))

$$F_{\gamma_t^d}(y) = \sum_{j=t}^{n} \binom{n}{j} \left[F_\gamma(y)\right]^j \left[1 - F(y)\right]^{(n-j)}$$

-------------------- (5)

- By replacing (4) into (5)

$$F_{\gamma_t^d}(y) = \sum_{j=t}^{n} \binom{n}{j} \left[1 - \frac{\Gamma\left(\omega_t, \frac{y}{\widehat{p_t}}\right)}{\Gamma(\omega_t)}\right]^j \left[\frac{\Gamma\left(\omega_t, \frac{y}{\widehat{p_t}}\right)}{\Gamma(\omega_t)}\right]^{(n-j)}$$

--------------------(6)

- By applying the binomial theorem, (6) becomes

$$F_{\gamma_t^d}(y) = \sum_{j=t}^{n} \binom{n}{j} \sum_{i=0}^{j} \binom{j}{i} (-1)^j \left[\sum_{k=0}^{\omega_{t-1}} \frac{1}{k!} \left(\frac{y}{\widehat{p_t}}\right)^k e^{-y/\hat{p}_t}\right]^\alpha$$

-------------(7)

- By using multinomial theorem, (7) becomes

$$F_{\gamma_t^d}(y) = \sum_{j=t}^{n} \binom{n}{j} \sum_{i=0}^{j} \binom{j}{i} (-1)^j \sum_{k_1, k_2 \ldots k_{\omega_t}}^{\alpha} \left(\frac{\alpha!}{k_1!\, k_2! \ldots k_{\omega_t}}\right) \prod_{t=0}^{\omega_{t-1}} \left[\frac{\left(\frac{1}{\widehat{p_t}}\right)^l}{l!}\right]^{k_{l+1}} \times y^{\omega_t + \sum_{t=0}^{\omega_{t-1}} l_{k_{l+1}}} e^{-\alpha\left(\frac{y}{\widehat{p_t}}\right)}$$

--------------- (8)

- Finally, with some algebraic manipulations

$$F_{\gamma_t^{d(y)}} = \sum_{j=t}^{n} \binom{n}{j} \sum_{i=0}^{j} \binom{j}{i} (-1)^j \sum_{k_1, k_2 \ldots k_{\omega_t}}^{\alpha} \left(\frac{\alpha!}{k_1!, k_2! \ldots k_{\omega_t}!}\right) \prod_{l=0}^{\omega_{t-1}} \left[\frac{\left(\frac{1}{\widehat{p_t}}\right)^l}{l!}\right]^{k_{l+1}} \times \frac{y^{\omega_t} + \sum_{t=0}^{\omega_{t-1}} l_{k_{l+1}}}{\sum_{t=0}^{\omega_{t-1}} \frac{y^t}{l!}} \frac{\gamma\left(\omega_t, \frac{\alpha y}{\widehat{p_t}}\right)}{\Gamma(\omega_t)}$$

-------------------- (9)

## III. Performance Analysis

The performance of present system can be validated by the following

1. *Outage probability analysis:* It is the probability by which SNR goes below a certain threshold $\gamma_{th}$. At the value below it, performance of the system becomes unacceptable. So, the outage probability can be written as

$$P_{out}(\gamma_{th}) = p_r(\gamma_t^d \leq \gamma_{th}) = F_{\gamma_t^d}(\gamma_{th})$$

------------ (10)

- By replacing (9)to(10) $p_{out}(\gamma_{th}) = \sum_{j=t}^{n}\binom{n}{j}\sum_{i=0}^{j}\binom{j}{i}(-1)^j \sum_{k_1,k_2\ldots k_{\omega_t}}^{\alpha}\left(\frac{\alpha!}{k_1!k_2!\ldots k_{\omega_t}!}\right)\prod_{l=0}^{\omega_t-1}\left[\frac{\left(\frac{1}{\widehat{\rho}_t}\right)^l}{l!}\right]^{k_{i+1}} \times$

*γthωt+t=0ωt−1lkl+1 t=0ωt−1γthll!γωt,αγthptγωt*

----------------- (11)

B. *Symbol Error Rate Analysis:*

From (13), the symbol error rate can be expressed as

$$S_{error} = \frac{A\sqrt{B}}{2\sqrt{\pi}}\int_0^{\infty} y^{-1/2}\, e^{-By} F_{\gamma_t^d}(y)dy$$

------------------ (12)

Where A, B are constants obtained from the specific modulation scheme. For binary Shift Keying (BPSK), A=B=1.

- By introducing (9) in (12)
- $S_{error} = \frac{A\sqrt{B}}{2\sqrt{\pi}}\sum_{j=t}^{n}\binom{n}{j}\sum_{i=0}^{j}\binom{j}{i}(-1)^j \sum_{k_1,k_2\ldots k_{wt}}^{\alpha}\left(\frac{\alpha!}{k_1!k_2!\ldots k_{wt}!}\right)\prod_{l=0}^{w_t-1}\left[\frac{\left(\frac{1}{\widehat{\rho}_t}\right)^l}{l!}\right]^{k_{l+1}} \int_0^{\infty} y^{-\frac{1}{2}} e^{-By} \times$

$y^{w_t+\sum_{l=0}^{w_t-1} l_{k_{l+1}}} e^{-\alpha\left(\frac{y}{\widehat{\rho}_t}\right)} dy.$

------------------ (13)

- Assume $I_1 = \int_0^{\infty} e^{-\left(B+\frac{\alpha}{\rho_t}\right)y} \times y^{w_{t-\frac{1}{2}}+\sum_{l=0}^{w_t-1} l_{k_{l+1}}} dy$
- So by using [21, eq.(2.33.10)] with some manipulations,

$$I_1 = \frac{-\Gamma(\frac{1}{2}+w_t+\sum_{l=0}^{w_t-1} l_{k_{l+1},}\left(\frac{\alpha}{\widehat{\rho}_t}+B\right)y)}{\left(\frac{\alpha}{\widehat{\rho}_t}+B\right)^{\frac{1}{2}+w_t+\sum_{l=0}^{w_t-1} l_{k_{l+1}}}}$$

------------------- (14)

- Finally, by substituting (14) in (13), the symbol error rate (13) becomes

$$S_{error} = \frac{A\sqrt{B}}{2\sqrt{11}}\sum_{j=t}^{n}\binom{n}{j}\sum_{i=0}^{j}\binom{j}{i}(-1)^j \sum_{k_1,k_2\ldots k_{wt}}^{\alpha}\left(\frac{\alpha!}{k_1!\,k_2!\ldots k_{wt}!}\right)\prod_{l=0}^{w_t-1}\left[\frac{\left(\frac{1}{\widehat{\rho}_t}\right)^l}{l!}\right]^{k_{l+1}} \int_0^{\infty} y^{-1/2}\, e^{-By} \times\left(\frac{-\Gamma(\frac{1}{2}+w_t+\sum_{l=0}^{w_t-1} l_{k_{l+1},}\left(\frac{\alpha}{\widehat{\rho}_t}+B\right)y)}{\left(\frac{\alpha}{\widehat{\rho}_t}+B\right)^{\frac{1}{2}+w_t+\sum_{l=0}^{w_t-1} l_{k_{l+1}}}}\right)$$

---------------- (15)

## IV. Simulation Results

The simulations are carried out in order to authenticate the accuracy of the numerical derivations with the simulation results. The SNR threshold $\gamma_{th}$ is assumed to be 3db and BPSK is incorporated in our system with a SCCP transmission. From all these figures we can observe the effects of variations in SNR, multipath components and the number of transmitters. $P_{Out}$ and $S_{error}$ are mathematically derived in (11) and (15), it is accurately deduced that the increase in SNR leads to a significant decrease in both $P_{Out}$ and $S_{error}$ which eventually leads to the enhancement of system performance. Moreover, altering the multipath components gives out a more remarkable variation on the system comparatively to a slight change caused by the increase of number of transmitters.

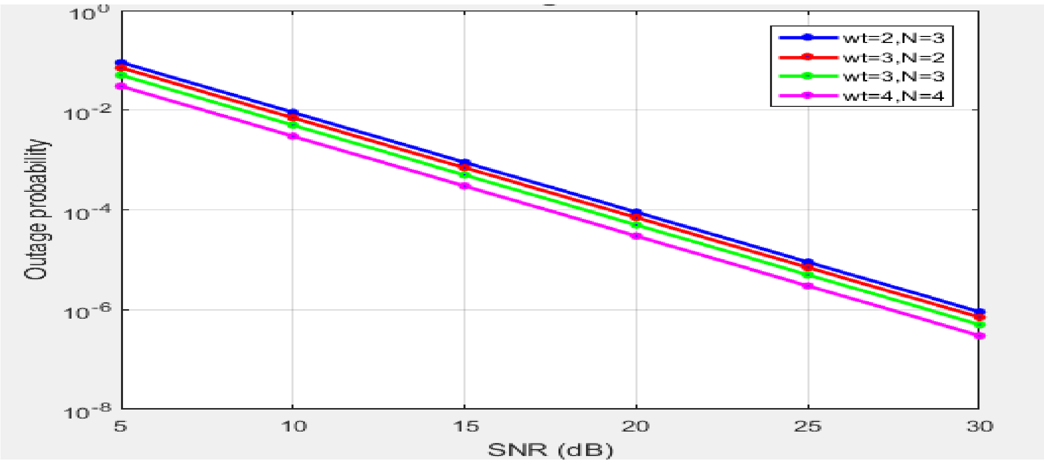


***Fig 4.1 :*** *Outage probability for several schemes with $\omega_t$*

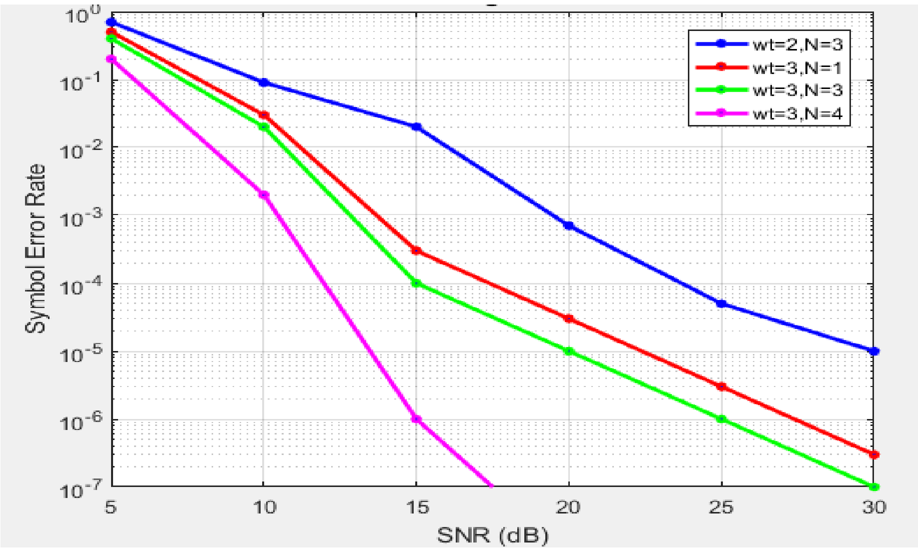


***Fig 4.2:*** *Symbol error rate of the proposed scheme for various values of multipath fading.*

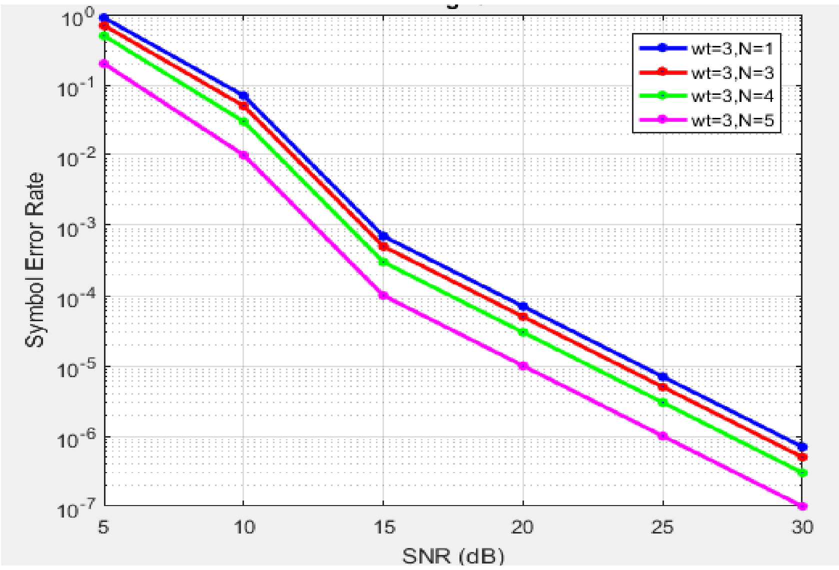


***Fig 4.3:*** *Symbol error rate for several scenarios with $\omega_t$=3.*

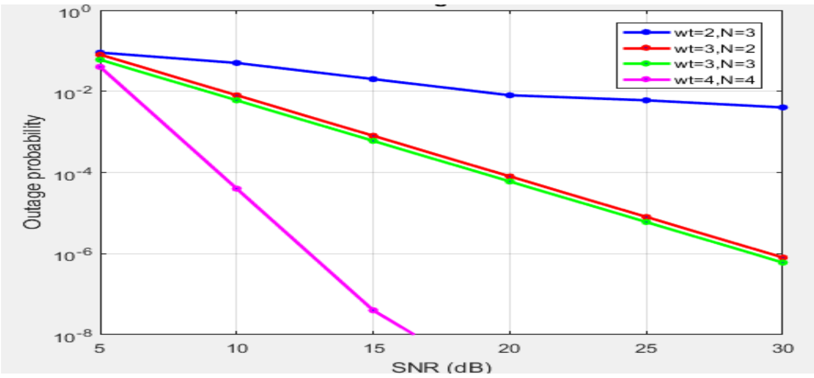


***Fig 4.4:*** *Outage probability of the proposed scheme for various values of multipath fading*

## V. Conclusions

In this paper, we suggested an approach of CDD-SCCP scheme to be incorporated in CRN, this method can give better results as space-time block coding and we went forward to study its closed-form expression of outage probability and symbol error rate. In a nutshell, our proposed scheme attained the full diversity gain and we noticed that the increase in the number of multipath components at the CRN lead to a phenomenal decrease in both the outage probability and the symbol error rate. In this method, in contrast to other spatial diversity methods such as the Alamouti scheme, there is no need to change the receiver in comparison to one antenna case. We have implemented the same strategy on a two-user SISO interference channel while treating interference as noise. Consequently, we reckoned that the system performance of CDD-SCCP scheme in CRN is distinctly enhanced proportionally to the level of number of multipath components.

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