Channel Capacity of Dual-Branch Maximal Ratio Combining under worst case of Fading Scenario

MOHAMMAD IRFANUL HASAN AND SANJAY KUMAR
Electronics and Communication Engineering
Birla Institute of Technology
Mesra, Ranchi (Jharkhand)
INDIA
irfu_hasan@rediffmail.com, skumar@bitmesra.ac.in

Abstract: - The worst case fading scenario can be represented by Nakagami-0.5 distribution, which is a special case of Nakagami-m fading distribution. Under Nakagami-0.5 fading distribution closed-form expressions have been derived for the average channel capacity using uncorrelated dual-branch maximal ratio combining (MRC). This channel capacity is evaluated under Optimum Power with Rate Adaptation (OPRA) and Truncated Channel Inversion with Fixed Rate transmission (TIFR) schemes. And Numerical results of the average channel capacity under OPRA and TIFR have been presented and compared. It has been observed that OPRA provides higher capacity than TIFR under worst case of fading.

Key-Words: - Dual-Branch, channel capacity, maximal ratio combining, Nakagami-0.5 fading channels, truncated channel inversion with fixed rate, optimum power with rate adaptation.

1 Introduction

The channel capacity implies the maximum achievable data rate of a system. Channel capacity is becoming increasingly a primary concern in the design of wireless mobile communication systems as the demand for wireless mobile communication services is growing rapidly [1]. The wireless mobile channels are subjected to fading, which is undesirable. The Channel capacity in fading environment can be improved by employing diversity combining and / or Adaptive transmission schemes [1-2]. Adaptive transmission requires accurate channel estimates at the receiver and a reliable feedback path between the receiver and the transmitter [1-2]. This helps in improving channel capacity. The capacities of flat fading channel have already been derived for four different adaptive transmission schemes such as OPRA, Optimum Rate Adaptation with constant transmit power (ORA), Channel Inversion with Fixed Rate transmission (CIFR) and TIFR [3]. In case of ORA scheme, the transmitter adapts only the data rate in accordance with channel fading conditions while the transmitted power remains constant [3].In case of OPRA scheme, transmitter can realize optimal capacity by transmitting appropriate power and data rate in accordance with the channel variations [3]. In CIFR scheme, transmitter adapts its power to maintain constant signal to noise ratio (SNR) at the receiver by inverting the channel gain, which makes the channel to appear as a time invariant additive white Gaussian noise (AWGN) channel [3]. Channel inversion with fixed rate suffers a large capacity penalty relative to the other techniques, since a large amount of power is required to compensate for the deep channel fades. A better approach is to use a modified inversion policy that inverts the channel fading only above a cut off fading level, which is called TIFR scheme [3].

Many research publications discuss the average channel capacity over Nakagami-m (for $m \geq 1$) fading channels under different adaptive transmission scheme and MRC [4-7]. In [1], average channel capacity of dual-branch MRC over correlated Nakagami-0.5 fading channels using ORA and CIFR is presented. However, analytical study of the dual-branch uncorrelated Nakagami-0.5 fading channels capacity under OPRA, and TIFR adaptation schemes has not been previously considered so far. This paper fills this gap by presenting an analytical performance study of the channel capacity of dual-branch MRC over uncorrelated Nakagami-0.5 fading channels using OPRA, and TIFR schemes.

In this paper, we consider dual-branch MRC, which offers the highest improvement in SNR at the output of the combiner [8].

The remainder of this paper is organized as follows: In Section 2, the channel model is defined. In Section 3, average channel capacity of dual-branch MRC over uncorrelated Nakagami-0.5 fading channels are derived for OPRA and TIFR schemes.

In Section 4, several numerical results are presented and analyzed, whereas in Section 5, concluding remarks are given.

2 Channel Model

We assume slowly-varying flat fading channels. Let us consider a $L-$branch MRC receiver operating over uncorrelated Nakagami-m fading channels. Thus the instantaneous received SNR(γ) at the combiner output is Nakagami-m distributed according to the pdf $(p_\gamma(\gamma))$ given by [4] as

$$p_\gamma(\gamma)=\frac{\gamma^{Lm-1}}{\Gamma(Lm)}\left(\frac{m}{\bar{\gamma}}\right)^{Lm}\exp\left(\frac{-m\gamma}{\bar{\gamma}}\right),\quad \gamma\geq 0\ \&\ m\geq 0.5 \qquad (1)$$

Where m the fading parameter, which measures the amount of fading, $\bar{\gamma}$ is the average received SNR which is assumed to be equal for each independent branch, L is the number of diversity branches, and $\Gamma(.)$ is the gamma function. For different values of m, this expression simplifies to several important distributions describing fading models. Like $m=0.5$ corresponds to the highest amount of fading, $m=1$ corresponds to Rayleigh distribution, $m\geq 1$ corresponds to Rician distribution, and as $m\to\infty$, the distribution converges to a nonfading AWGN [9].

Considering no diversity $(i.e\ L=1)$ the pdf under worst case of fading (i.e. $m=0.5$) using (1) is

$$p_\gamma(\gamma)=\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}},\quad \gamma\geq 0 \qquad (2)$$

Considering dual-branch MRC $(i.e\ L=2)$ the pdf under worst case of fading using (1) is

$$p_\gamma(\gamma)=\frac{1}{2\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right),\quad \gamma\geq 0 \qquad (3)$$

3 Average Channel Capacity

In this section, we present closed-form expressions for the average channel capacity of uncorrelated Nakagami-0.5 fading channels with dual-branch MRC and no diversity under OPRA, and TIFR schemes. It is assumed that, for the above considered adaptation schemes, there exist perfect channel estimation and an error-free delayless feedback path, similar to the assumption made in [6].

3.1 OPRA

The average channel capacity of fading channel with received SNR distribution $p_\gamma(\gamma)$ under OPRA scheme (C_{OPRA} [bit/sec]) is defined in [3-4] as

$$C_{OPRA}=B\int_{\gamma_0}^{\infty}\log_2\left(\frac{\gamma}{\gamma_0}\right)p_\gamma(\gamma)\,d\gamma \qquad (4)$$

Where B [Hz] is the channel bandwidth and γ_0 is the optimum cut off SNR level below which data transmission is suspended. This optimum cut off must satisfy the equation given by [3-4] as

$$\int_{\gamma_0}^{\infty}\left(\frac{1}{\gamma_0}-\frac{1}{\gamma}\right)p_\gamma(\gamma)\,d\gamma \qquad (5)$$

To achieve the capacity (4), the channel fade level must be tracked at both the receiver and transmitter, and the transmitter has to adapt its power and rate accordingly, allocating high power levels and rate for good channel conditions (γ large), and lower power levels and rates for unfavorable channel conditions (γ small).

When $\gamma<\gamma_0$, no data is transmitted, the optimal scheme suffers a probability of outage P_{out}, equal to the probability of no transmission, given by [3-4] is

$$P_{out}=\int_0^{\gamma_0}p_\gamma(\gamma)\,d\gamma=1-\int_{\gamma_0}^{\infty}p_\gamma(\gamma)\,d\gamma \qquad (6)$$

3.1.1 No Diversity

Substituting (2) in (5), the cut off SNR level γ_0 must satisfy

$$\int_{\gamma_0}^{\infty}\left(\frac{1}{\gamma_0}-\frac{1}{\gamma}\right)\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}}\,d\gamma=1$$

Evaluating the above integral and after some mathematical transformation using [10], we obtain

$$\left[\frac{1}{\gamma_0}+\frac{1}{\bar{\gamma}}\right]erfc\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right)-\sqrt{\frac{2}{\pi\gamma_0\bar{\gamma}}}\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right)=1 \qquad (7)$$

Where $erfc(.)$ is the complementary error function.

The numerical value of γ_0, which satisfies (7) can be calculated using MATLAB, result shows that γ_0 increases as $\bar{\gamma}$ increases and γ_0 always lies in the interval [0, 1]. The value of cut off SNR γ_0 that satisfy (7) for each $\bar{\gamma}$ is used for finding average channel capacity per unit bandwidth.

Substituting (2) into (4), the average channel capacity becomes

$$C_{OPRA}=B\int_{\gamma_0}^{\infty}\log_2\left(\frac{\gamma}{\gamma_0}\right)\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}}\,d\gamma$$

$$C_{OPRA} = \frac{1.443B}{\sqrt{2\pi\bar{\gamma}}} \int_{\gamma_0}^{\infty} \log\left(\frac{\gamma}{\gamma_0}\right) \frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{\gamma}} d\gamma$$

The above integral can be solved using partial integration as follows

$$\int_{\gamma_0}^{\infty} u dv = uv\Big|_{\gamma_0}^{\infty} - \int_{\gamma_0}^{\infty} v du$$

Let $u = \log\left(\frac{\gamma}{\gamma_0}\right)$

then $du = \frac{d\gamma}{\gamma}$

Now let $dv = \frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{\gamma}} d\gamma$

then $v = \sqrt{2\pi\bar{\gamma}}\, erf\left[\sqrt{\frac{0.5\gamma}{\bar{\gamma}}}\right]$

After evaluating the above integral by using partial integration and some mathematical transformation using [10-11], we obtain

$$C_{OPRA} = 1.443B \left[\begin{array}{l} erf\left(\sqrt{\frac{0.5\gamma}{\bar{\gamma}}}\right)\log\left(\frac{\gamma}{\gamma_0}\right) \\ -\sqrt{\frac{8\gamma}{\pi\bar{\gamma}}}\; {}_2F_2\left(0.5,0.5;1.5,1.5;\frac{-0.5\gamma}{\bar{\gamma}}\right) \end{array} \right]_{\gamma_0}^{\infty}$$

Where ${}_2F_2(.,.;.,.;.)$ is the generalized hypergeometric function and $erf(.)$ is the error function.

Using that result we obtain average channel capacity per unit bandwidth i.e. $\frac{C_{OPRA}}{B}$ [bit/sec/Hz] as

$$\frac{C_{ORA}}{B} = 1.443 \left[\begin{array}{l} erf\left(\sqrt{\frac{0.5\gamma}{\gamma_0}}\right)\log\left(\frac{\gamma}{\gamma_0}\right) \\ -\sqrt{\frac{8\gamma}{\pi\bar{\gamma}}}\; {}_2F_2\left(0.5,0.5;1.5,1.5;\frac{-\gamma}{2\bar{\gamma}}\right) \end{array} \right]_{\gamma_0}^{\infty} \quad (8)$$

Substituting (2) in (6) for probability of outage, then

$$P_{out} = \int_{0}^{\gamma_0} \frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}} d\gamma$$

After evaluating the above integral by using mathematical transformation using [10], we obtain

$$P_{out} = erf\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right) \quad (9)$$

3.1.2 Dual-Branch MRC

Substituting (3) in (5) for optimal cut off SNR γ_0 then

$$\int_{\gamma_0}^{\infty} \left(\frac{1}{\gamma_0} - \frac{1}{\gamma}\right) \frac{\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right)}{2\bar{\gamma}} d\gamma = 1$$

Evaluating the above integral using some mathematical transformation by [10], we obtain

$$\frac{\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right)}{\gamma_0} - \frac{E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right)}{2\bar{\gamma}} = 1 \quad (10)$$

The numerical value of γ_0, which satisfies (10) can be calculated using MATLAB, result shows that γ_0 increases as $\bar{\gamma}$ increases and γ_0 always lies in the interval [0, 1]. The value of cut off SNR γ_0 that satisfies (10) for each $\bar{\gamma}$ is used for finding average channel capacity per unit bandwidth.

Substituting (3) in (4), the average channel capacity of dual-branch MRC under Nakagami-0.5 fading channel is

$$C_{OPRA} = B \int_{\gamma_0}^{\infty} \log_2\left(\frac{\gamma}{\gamma_0}\right) \frac{1}{2\bar{\gamma}} \exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) d\gamma$$

$$C_{OPRA} = \frac{1.443B}{2\bar{\gamma}} \int_{\gamma_0}^{\infty} \log\left(\frac{\gamma}{\gamma_0}\right) \exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) d\gamma$$

The above integral can be solved using partial integration as follows

$$\int_{\gamma_0}^{\infty} u\, dv = uv\Big|_{\gamma_0}^{\infty} - \int_{\gamma_0}^{\infty} v\, du$$

Let $u = \log\left(\frac{\gamma}{\gamma_0}\right)$

then $du = \frac{d\gamma}{\gamma}$

Now let $dv = \exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right) d\gamma$

$$v = -2\bar{\gamma} \exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right)$$

Evaluating integral by using above partial integration and some mathematical transformation using [10], we obtain

$$C_{OPRA} = 1.443\, B\, E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right), \qquad \gamma \geq 0$$

Where $E_1(.)$ is the exponential integral of first order.

Using that result we obtain average channel capacity per unit bandwidth i.e. $\frac{C_{OPRA}}{B}$ [bit/sec/Hz] as

$$\frac{C_{OPRA}}{B} = 1.443 E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right), \qquad \gamma \geq 0 \quad (11)$$

Substituting (3) in (6) for probability of outage, then

$$P_{out} = \int_{0}^{\gamma_0} \frac{1}{2\bar{\gamma}} \exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) d\gamma$$

After evaluating the above integral by using mathematical transformation using [10], we obtain

$$P_{out} = 1 - \exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right) \tag{12}$$

3.2 TIFR

The average channel capacity of fading channel with received SNR distribution $p_\gamma(\gamma)$ under TIFR scheme (C_{TIFR} [bit/sec]) is defined in [3-4] as

$$C_{TIFR} = B\log_2\left(1 + \frac{1}{\int_{\gamma_0}^{\infty}\left(\frac{p_\gamma(\gamma)}{\gamma}\right)d\gamma}\right)(1 - P_{out}), \quad \gamma \ge 0 \tag{13}$$

Where γ_0 is a fixed cut off level above which TIFR inverts the channel fading and P_{out} is the probability of outage, equal to the probability of no transmission, given by [3-4] as

$$P_{out} = P[\gamma \le \gamma_0] = \int_0^{\gamma_0} p_\gamma(\gamma)\,d\gamma = 1 - \int_{\gamma_0}^{\infty} p_\gamma(\gamma)\,d\gamma \tag{14}$$

The cut off level γ_0 can be selected to achieve a specified probability of outage or, alternatively, to maximize (14).

3.2.1 No Diversity

The pdf of no diversity under Nakagami-0.5 fading channel is given in (2) as

$$p_\gamma(\gamma) = \frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}}, \quad \gamma \ge 0$$

Hence,

$$\frac{p_\gamma(\gamma)}{\gamma} = \frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}} \times \frac{1}{\gamma}, \quad \gamma \ge 0 \tag{15}$$

Integrating the (15) over an interval as shown below

$$\int_{\gamma_0}^{\infty}\frac{p_\gamma(\gamma)}{\gamma}\,d\gamma = \int_{\gamma_0}^{\infty}\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}}} \times \frac{1}{\gamma^{1.5}}\,d\gamma$$

Evaluating integral by some mathematical transformation using [10], we obtain

$$\int_{\gamma_0}^{\infty}\frac{p_\gamma(\gamma)}{\gamma}\,d\gamma = \frac{1}{\sqrt{2\pi\bar{\gamma}}}\left(-\sqrt{\frac{2\pi}{\bar{\gamma}}}\,erf\left(\sqrt{\frac{0.5\gamma}{\bar{\gamma}}}\right) - \frac{2\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{\gamma}}\right)\Bigg|_{\gamma_0}^{\infty}$$

$$\int_{\gamma_0}^{\infty}\frac{p_\gamma(\gamma)}{\gamma}\,d\gamma = \frac{1}{\sqrt{2\pi\bar{\gamma}}}\left(\lim_{\gamma\to\infty}\left(-\sqrt{\frac{2\pi}{\bar{\gamma}}}\,erf\left(\sqrt{\frac{0.5\gamma}{\bar{\gamma}}}\right) - \frac{2\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{\gamma}}\right) - \lim_{\gamma\to\gamma_0}\left(-\sqrt{\frac{2\pi}{\bar{\gamma}}}\,erf\left(\sqrt{\frac{0.5\gamma}{\bar{\gamma}}}\right) - \frac{2\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{\gamma}}\right)\right)$$

After evaluating the limit we obtain the above integral as

$$\int_{\gamma_0}^{\infty}\frac{p_\gamma(\gamma)}{\gamma}\,d\gamma = \frac{1}{\sqrt{2\pi\bar{\gamma}}}\left[-\sqrt{\frac{2\pi}{\bar{\gamma}}}\,erfc\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right) + \frac{2\exp\left(\frac{-0.5\gamma_0}{\bar{\gamma}}\right)}{\sqrt{\gamma_0}}\right] \tag{16}$$

Now, we evaluate the probability of outage using (2) in (14) as

$$P_{out} = 1 - \int_{\gamma_0}^{\infty}\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}}\,d\gamma$$

$$1 - P_{out} = \int_{\gamma_0}^{\infty}\frac{\exp\left(\frac{-0.5\gamma}{\bar{\gamma}}\right)}{\sqrt{2\pi\bar{\gamma}\gamma}}$$

Evaluating integral by some mathematical transformation using [10], we obtain

$$1 - P_{out} = erfc\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right) \tag{17}$$

Putting the value of (16) and (17) in (13), we get

$$C_{TIFR} = 1.443B\log\left[1 + \frac{\bar{\gamma}\sqrt{2\pi\gamma_0}}{\left(2\sqrt{\bar{\gamma}}\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right) - \sqrt{2\pi\gamma_0}\,erfc\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right)\right)}\right] \times erfc\left(\sqrt{\frac{0.5\gamma}{\gamma_0}}\right)$$

Using that result we obtain average channel capacity per unit bandwidth i.e. $\frac{C_{TIFR}}{B}$ [bit/sec/Hz] as

$$\frac{C_{TIFR}}{B} = 1.443 \log\left[1 + \frac{\bar{\gamma}\sqrt{2\pi\gamma_0}}{\left(2\sqrt{\bar{\gamma}}\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right) - \sqrt{2\pi\gamma_0}\,erfc\left(\sqrt{\frac{0.5\gamma_0}{\bar{\gamma}}}\right)\right)}\right] \times erfc\left(\sqrt{\frac{0.5\gamma}{\gamma_0}}\right) \tag{18}$$

3.2.2 Dual-Branch MRC

The pdf of dual-branch MRC under uncorrelated Nakagami-0.5 fading channels is given in (3) as

$$p_\gamma(\gamma) = \frac{1}{2\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right), \quad \gamma \geq 0$$

Hence

$$\frac{p_\gamma(\gamma)}{\gamma} = \frac{1}{2\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) \times \frac{1}{\gamma}, \quad \gamma \geq 0 \tag{19}$$

Integrating the (19) over an interval as shown below

$$\int_{\gamma_0}^{\infty} \frac{p_\gamma(\gamma)}{\gamma}\, d\gamma = \int_{\gamma_0}^{\infty} \frac{1}{2\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) \times \frac{1}{\gamma}\, d\gamma$$

Evaluating the above integral using mathematical transformation by [10], we obtain

$$\int_{\gamma_0}^{\infty} \frac{p_\gamma(\gamma)}{\gamma}\, d\gamma = \frac{1}{2\bar{\gamma}}\left(E_i\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right)\right)_{\gamma_0}^{\infty}$$

Where exponential integral $E_i(.)$ is defined by [10] as

$$E_1(x) = -E_i(-x) \qquad for\ x > 0$$

After evaluating the limit using [7], we obtain the above integral as

$$\int_{\gamma_0}^{\infty} \frac{p_\gamma(\gamma)}{\gamma}\, d\gamma = \frac{1}{2\bar{\gamma}}\, E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right) \tag{20}$$

Now we evaluate the outage probability using (3) in (14) as

$$P_{out} = 1 - \int_{\gamma_0}^{\infty} \frac{0.5}{\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) d\gamma$$

$$1 - P_{out} = \int_{\gamma_0}^{\infty} \frac{0.5}{\bar{\gamma}}\exp\left(-\frac{0.5\gamma}{\bar{\gamma}}\right) d\gamma$$

After integrating we get

$$1 - P_{out} = \exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right) \tag{21}$$

Putting the value of (20) and (21) in (13), we get

$$C_{TIFR} = 1.443B\log\left[1 + \frac{2\bar{\gamma}}{E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right)}\right]\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right)$$

Using that result we obtain average channel capacity per unit bandwidth i.e. $\frac{C_{TIFR}}{B}$ [bit/sec/Hz] as

$$\frac{C_{TIFR}}{B} = 1.443\log\left[1 + \frac{2\bar{\gamma}}{E_1\left(\frac{0.5\gamma_0}{\bar{\gamma}}\right)}\right]\exp\left(-\frac{0.5\gamma_0}{\bar{\gamma}}\right) \tag{22}$$

4 Numerical Results and Analysis

In this section, various performance evaluation results for the average channel capacity per unit bandwidth obtained using dual-branch MRC as well as without diversity operating over uncorrelated Nakagami-0.5 fading channels has been presented and analyzed. These results also compare the different adaptive transmission schemes under Nakagami-0.5 fading channel condition.

In Fig.1, the average channel capacity per unit bandwidth under OPRA scheme is plotted as a function of the average received SNR per branch $\bar{\gamma}$. As expected, by increasing $\bar{\gamma}$ and/or employing diversity, average channel capacity per unit bandwidth improves.

In Fig.2, the probability of outage under OPRA scheme is plotted as a function of the average received SNR per branch $\bar{\gamma}$. As expected, by increasing $\bar{\gamma}$ and/or employing diversity, probability of outage improves.

In Fig.3, the average channel capacity per unit bandwidth under TIFR scheme is plotted as a function of average received SNR per branch $\bar{\gamma}$. As expected, by increasing $\bar{\gamma}$ and/or employing diversity, average channel capacity per unit bandwidth improves.

In Fig.4, the probability of outage under TIFR scheme is plotted as a function of the average received SNR per branch $\bar{\gamma}$. As expected, by increasing $\bar{\gamma}$ and/or employing diversity, probability of outage improves.

In Fig.5, the average channel capacity per unit bandwidth of no diversity under TIFR scheme is plotted as a function of the cut off SNR γ_0 for several values of the average received SNR per branch $\bar{\gamma}$. As expected by increasing $\bar{\gamma}$, average channel capacity per unit bandwidth improves.
In Fig.6, the average channel capacity per unit bandwidth of dual-branch MRC under TIFR scheme is plotted as a function of the cut off SNR γ_0 for several values of the average received SNR per branch $\bar{\gamma}$. As expected, by increasing $\bar{\gamma}$ and/or employing diversity, average channel capacity per unit bandwidth improves.
In Fig.7, the average channel capacity per unit bandwidth of uncorrelated Nakagami-0.5 fading channels with and without diversity is plotted as a function of $\bar{\gamma}$,considering OPRA, and TIFR adaptation schemes with the aid of (8),(11),(18),and (22). It shows that, for Nakagami-0.5 fading channel condition OPRA achieves the highest capacity, whereas TIFR achieves the lowest capacity. As expected by increasing $\bar{\gamma}$ the channel capacity difference between OPRA and TIFR adaptation scheme increases more significantly in dual-branch MRC since probability of outage improves. It can also be observed that the channel capacity difference between OPRA and TIFR adaptation scheme for no diversity become almost negligible for smaller values of the average received SNR i.e. $\bar{\gamma} = -10\,dB$, compared with the dual-branch MRC.
In Fig.8, it is depicted that for the Nakagami-0.5 fading conditions, OPRA achieves improved probability of outage compared to TIFR. It can also be observed that the outage probability of TIFR for dual-branch MRC become almost identical to the outage probability of OPRA with no diversity for smaller values of the average received SNR i.e. $\bar{\gamma} < -1\,dB$.

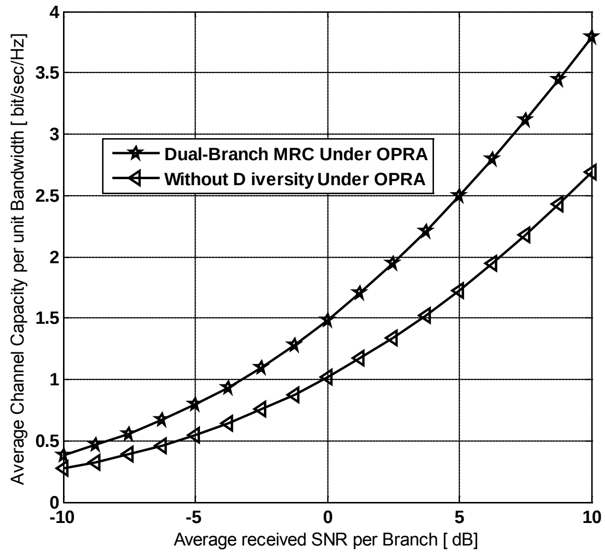

Fig.1. Average channel capacity per unit bandwidth for a Nakagami-0.5 fading versus average received SNR.

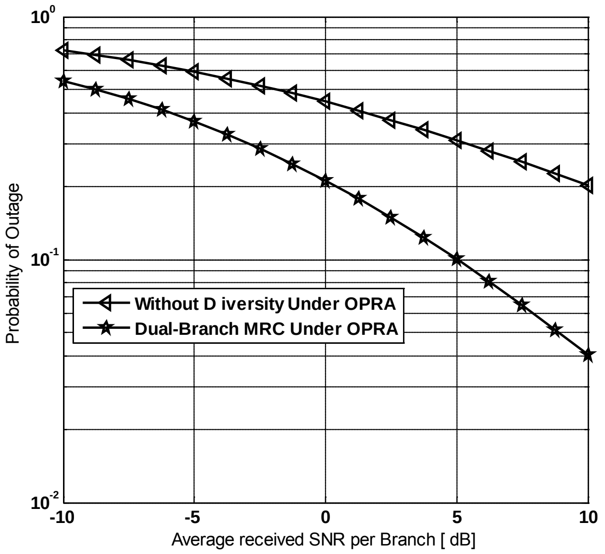

Fig.2. Outage probability for a Nakagami-0.5 fading versus average received SNR.

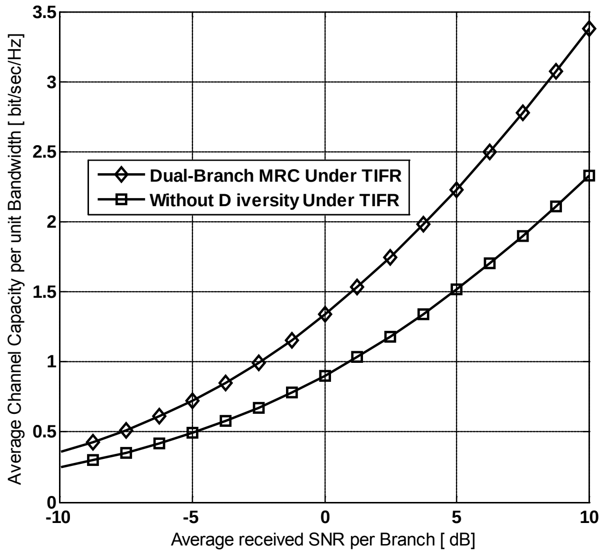

Fig.3. Average channel capacity per unit bandwidth for a Nakagami-0.5 fading versus average received SNR.

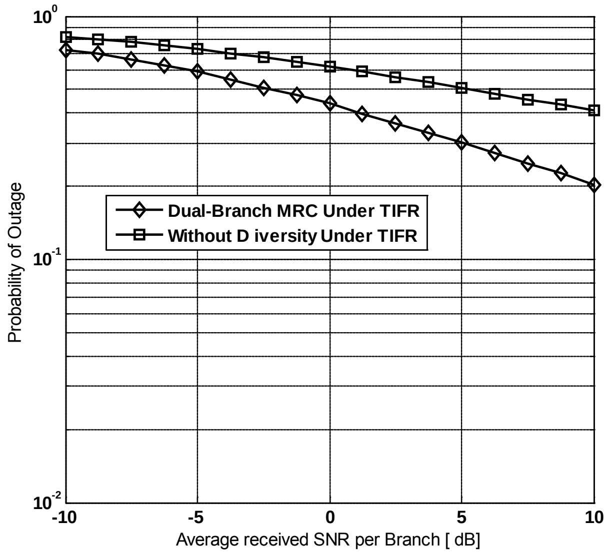

Fig.4. Outage probability for a Nakagami-0.5 fading versus average received SNR.

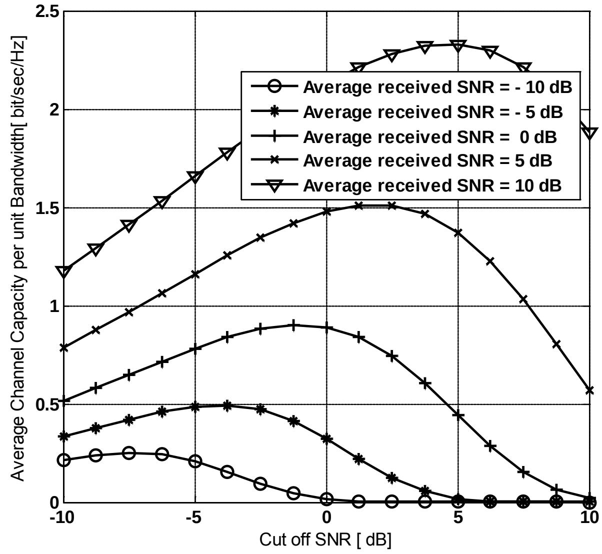

Fig.5. Average channel capacity per unit bandwidth under the TIFR scheme versus the cut off SNR for several values of average received SNR with no Diversity.

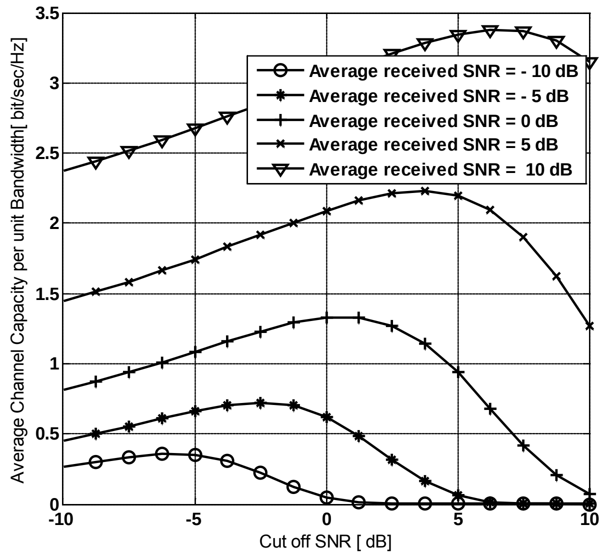

Fig.6. Average channel capacity per unit bandwidth under the TIFR scheme versus the cut off SNR for several values of average received SNR with dual-branch MRC.

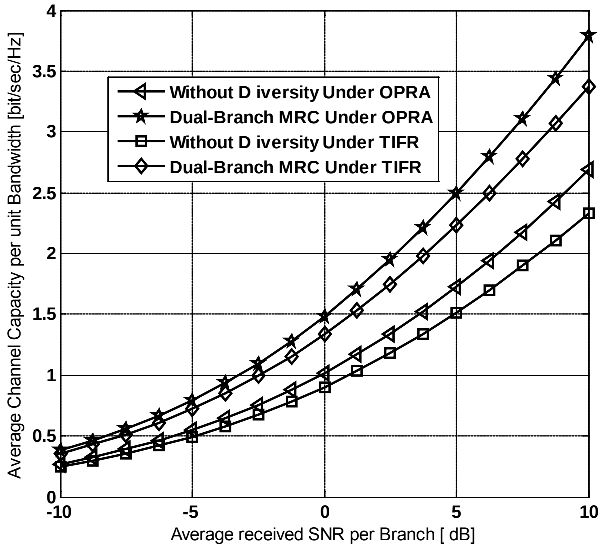

Fig.7. Average channel capacity per unit bandwidth for a Nakagami-0.5 fading versus average received SNR under different adaptation schemes.

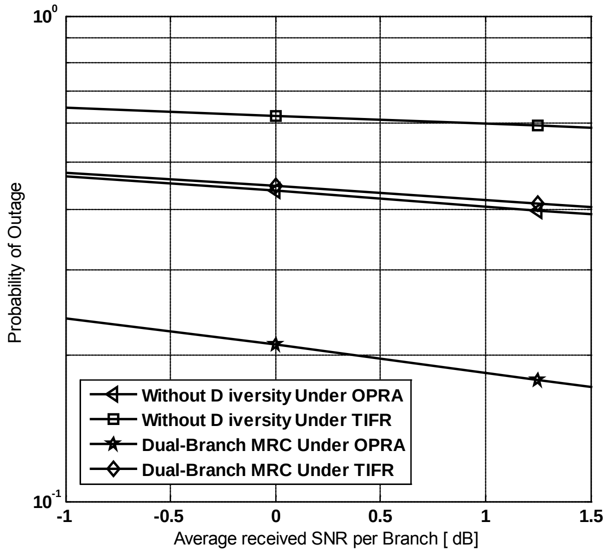

Fig.8. Outage probability for a Nakagami-0.5 fading versus average received SNR under different adaptation scheme.

5 Conclusion

In this paper, we analyze the average channel capacity of dual-branch MRC and no diversity over slowly varying uncorrelated Nakagami-0.5 fading channels for OPRA and TIFR schemes. Closed-form expressions for the average channel capacity of dual-branch MRC and no diversity for OPRA and TIFR schemes have been obtained. Numerically evaluated results have been plotted and compared. It has been found that by increasing $\bar{\gamma}$ and/or employing diversity, average channel capacity improves for both the case OPRA and TIFR. But the amount of improvement is larger in case of OPRA. Outage probability of dual-branch MRC using TIFR is higher compared to Outage probability of dual-branch MRC using OPRA. It has been observed that with increase of $\bar{\gamma}$ the outage probability of TIFR scheme using dual-branch MRC gives inferior performance over the outage probability of OPRA scheme using no diversity but almost identical for smaller value of $\bar{\gamma}$.

REFERENCES

[1] S. Khatalin and J.P.Fonseka, Channel Capacity of dual- branch diversity systems over correlated Nakagami-m fading with channel inversion and fixed rate transmission scheme, *IET Communication Proc.*,Vol.1,No.6, 2007,pp.1161-1169.
[2] S. Khatalin and J.P.Fonseka, Capacity of correlated Nakagami-m Fading Channels with Diversity Combining Techniques, *IEEE Trans. Veh. Technol*., Vol.55, No.1, 2006, pp.142-150.
[3] A.J.Goldsmith and P.P.Varaiya, Capacity of fading channels with channel side information,*IEEE Trans. Inform. Theory*, Vol.43,No.6, 1997, pp. 1986-1992.
[4] M .S. Alouini and A.J.Goldsmith, Capacity of Nakagami multipath fading channels, *Proc. IEEE Veh. Technol.Conf.*, Phoenix, AZ, 1997, pp.358-362.
[5] M .S. Alouini and A.J. Goldsmith, Capacity of Rayleigh fading channels under different adaptive transmission and diversity-combining techniques, *IEEE Trans. Veh. Technol*., Vol.48, No.4, 1999, pp.1165-1181.
[6] P.S.Bithas, P.T.Mathiopoulos, Capacity of Correlated Generalized Gamma Fading with Dual-Branch Selection Diversity,*IEEE Trans. Veh. Technol.*, Vol.58, No.9, 2009, pp.5258-5263.
[7] M .S. Alouini and A. Goldsmith, Adaptive modulation over Nakagami fading channels, *Wireless Presonal Communication*, Vol.13, 2000, pp.119-143.
[8] D. Brennan, Linear Diversity Combining techniques, *Proc. IEEE*, vol.91, No.2, 2003, pp.331-354.
[9] M. K. Simon and M. S. Alouini, *Digital Communication over Fading Channels*, John

Wiley & Sons, 2005.
[10] I. S. Gradshteyn and I. M. Ryzhik, *Tables of Integrals, series, and Products*, Academic Press, 2000.
[11]Wolfram, The Wolfram functions site (2004), Internet (online), http://functions.wolfram.com.