5.1 INTRODUCTION

Recently, OFDM is considered as an effective approach for the high-speed wireless multimedia communication systems due to its robustness against the multipath delay spread, feasibility in hardware implementation, flexibility in subcarrier allocation and adaptability in the subcarrier modulation [2]. Unfortunately, the integrity of digital communication in various mobile applications is subject to detrimental effects of multipath fading as an intrinsic characteristic of the most wireless channels. The growing demand for wireless communication makes it important to determine the capacity limits of the underlying channels for the communication systems. In 1948, Shannon has provided a mathematical theory of communication underlying channel capacity. He defined that channel capacity is the maximum data rates that can be transmitted over wireless channels with small error probability, assuming no constraints on delay or complexity of the encoder and decoder. In the wireless communication systems, fading is an important phenomenon, as discussed in previous chapter. In this chapter, we have discussed the effect of multipath fading on the channel capacity.

![System model for flat fading channel.](image)

**Figure 5.1** System model for flat fading channel.

The system model for the flat fading is shown in Figure 5.1, where $d$ is an input signal that is sent from transmitter to receiver, $\hat{d}$ is an estimated signal of transmitted...
signal $d$. If the transmitted message is coded into code word $e$ and transmitted over time varying channel as $c[i]$ at any time $i$. The channel gain $g[i]$ is also called as channel side information (CSI), which changes during transmission of code word [30]. The channel capacity of any channel depends on that is known about $g[i]$ at the transmitter and receiver [30]. On the basis of channel knowledge, three different scenarios are discussed below.

1. **Channel distribution information (CDI):** The distribution of $g[i]$ is known to the transmitter and receiver.

2. **Receiver CSI:** The value of $g[i]$ is known to the receiver at time $i$, and both the transmitter and receiver know the distribution of $g[i]$.

3. **Transmitter and receiver CSI:** The value of $g[i]$ is known to the transmitter and receiver.

In this Chapter mainly, three type of the channel capacity is discussed on the basis of channel side information at the transmitter and receiver. In general, the channel capacity in fading channel is a complex expression in terms of the channel variation in time and/or frequency depending also upon the transmitter and/or receiver knowledge of the channel side information. For the various channel side information assumptions that have been proposed, several definitions of the channel capacity have been provided. These definitions depend on the different employed power and rate adaptation policies and the existence, or not, an outage probability [22]. Earlier, the capacity has been studied by various researchers for several fading environment [104-116,153]. Goldsmith and Varaiya [104] have examined the channel capacity of the Rayleigh fading channels under different adaptive transmission techniques. Lee [105] has derived an expression for the channel capacity of a Rayleigh fading channel. Gunther [106] has extended the results presented in [105] by deriving the channel capacity of Rayleigh fading channels under diversity scheme. In [107], Alouini and Goldsmith have derived the channel capacity of Rayleigh fading channels under different diversity schemes and different rate adaptation and transmit power schemes. Other fading channels like Nakagami, Weibull, Rician, and Hoyt fading channels were studied in [108-109]. Khatalin and Fonseka [110] have been discussed the channel capacity for correlated Nakagami-m fading channel by using the dual diversity. In [111], the characteristics function (CF) is developed for computing the
ergodic channel capacity. In [153], the channel capacity under different diversity schemes and different rate adaptation and transmit power schemes for the correlated Rayleigh have been derived. In [112-115], the moment generating function based (MGF) approach is proposed for computation of channel capacity only for C_{ora} scheme, by using the numerical techniques. In [116] a novel MGF based approach is developed for evaluation of channel capacity various rate adaptation and transmit power. In [116] the integral is evaluated by using mainly two type of numerical technique and both the numerical techniques are lengthy and much more complex. In [154] the channel capacity limit for fading channel is discussed.

In this Chapter, we have presented a marginal moment generating (MMGF) based channel capacity analysis over correlated Nakagami-m fading channel with M-branch maximal-ratio combining (MRC) diversity. This chapter consists of the evaluation the MMGF function and the derived MMGF function is used to evaluate a closed-form expression for the channel capacity under optimal rate adaptation (C_{ORA}), channel capacity with optimal simultaneous power and rate adaptation (C_{OPRA}), channel inversion with fixed rate (C_{CINV}) and truncated CIFR is approach (C_{TFR}). The results obtained for these channel capacities are discussed in the terms of well known Meijer G function and other special functions, which can be easily implemented by using Maple or Mathematica software.

5.2. SYSTEM MODEL

We have considered the average power signal as well as fading parameters in each M-channels of a MRC system that is identical. The assumption of identical power is reasonable if the diversity channels are closely spaced and the gain of each channel is such that all the noise power is equal [148]. The signal-to-noise ratio at the output of MRC diversity is given by [148]. When receiving antennas are closely spaced then receiving signal are also correlated and SNR of received signal \( \gamma_1, \gamma_2, \ldots, \gamma_M \) cannot be considered as independent random variable. The probability density function of \( \gamma_i \) for correlated Nakagami-\( m \) fading as given by Equation (4.5) is:
\[ P_\gamma (\gamma_t) = \frac{A}{D} e^{-B\gamma_t} F_1\left(m, M\gamma_t, C\gamma_t; \gamma_t\right)^{m+1} \quad (5.1) \]

\[ A = \left(\frac{m}{\gamma_t}\right)^{\lambda m} \quad B = \frac{m}{\gamma_t(1-\rho)} \quad C = \frac{M m \rho}{\gamma_t (1-\rho)(1-\rho+M\rho)} \quad \text{and} \]

\[ D = (1-\rho)^{m(M-1)} (1-\rho+M\rho)^m \Gamma(M m) \]

**5.3 Marginal moment evaluation**

In this Section, MMGF is evaluated of the SNR of M-branch MRC diversity and further, it is used for the computation of channel capacity. The MMGF is defined as [155]:

\[ \hat{M}(s, a) = \frac{\gamma_t}{a} e^{a\gamma_t} f_\gamma (\gamma) d\gamma \quad (5.2) \]

By substituting the value of \( f_\gamma (\gamma) \) from the Equation (5.1) in Equation (5.2), we get:

\[ \hat{M}(s, a) = \frac{A}{D} \int_{\gamma_t}^{\infty} (\gamma_t)^{\lambda m-1} e^{-B\gamma_t} F_1\left(m, M\gamma_t, C\gamma_t, \gamma_t\right)^{m+1} d\gamma_t \quad (5.3) \]

By expanding \( F_1(\cdot) \) from [149 Equation (9.14.1)] and putting in Equation (5.3), we get:

\[ \hat{M}(s, a) = \frac{A}{D} \sum_{k=0}^{\infty} \frac{\Gamma(k+m)\Gamma(Mm)}{\Gamma(m)\Gamma(k+Mm)} \frac{(C)^k}{k!} I_k \quad (5.4) \]

where

\[ I_k = \left(\frac{\gamma_t}{a}\right)^{k+Mm-1} e^{-(k+M\rho)\gamma_t} d\gamma_t \quad (5.5) \]

From [149 Equation (3.381.3)], the Equation (5.5) can be written as:

\[ I_k = (B+s)^{-(k+Mm)} \Gamma(k + m M, a(B+s)) \quad (5.6) \]

By putting the result of \( I_k \) from Equation (5.5) to Equation (5.4), we get:

\[ \hat{M}(s, a) = \frac{A}{D} \sum_{k=0}^{\infty} \frac{\Gamma(k+m)\Gamma(Mm)}{\Gamma(m)\Gamma(k+Mm)} \frac{(C)^k}{k!} \frac{\Gamma(k + m M, a(B+s))}{(B+s)^{k+Mm}} \quad (5.7) \]

By putting \( a = 0 \) in Equation (5.7), the marginal MGF changes to moment generating function(MGF) as:
\[ M(s) = \frac{A}{D} \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m) \Gamma(k + Mm)} \frac{(C)^k}{k!} \frac{\Gamma(k + m)\Gamma(k + Mm)}{(B + s)^{m(k + Mm)}} \]

\[ = \frac{A}{D} \frac{\Gamma(Mm)}{(B + s)^{Mm}} \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m) \Gamma(k + Mm)} \frac{1}{k!} \left( \frac{C}{B + s} \right)^k \]

\[ M(s) = \frac{A}{D} \left( \frac{\Gamma(Mm)}{(B + s)^{Mm}} \right) \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m) \Gamma(k + Mm)} \frac{1}{k!} \left( \frac{C}{B + s} \right)^k \] (5.8)

From [149 Equation (7.621.4)] table of integral, we get:

\[ M(s) = \frac{A}{D} \left( \frac{\Gamma(Mm)}{(B + s)^{Mm}} \right) \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m) \Gamma(k + Mm)} \frac{1}{k!} \left( \frac{C}{B + s} \right)^k \] (5.9)

From [156 Equation (15.1.8)], the Equation can be expressed as:

\[ M(s) = \left( 1 + \frac{z(1 - \rho + M\rho)}{m} \right)^{-m} \left( 1 + \frac{z(1 - \rho)}{m} \right)^{-m(M - 1)} \] (5.10)

MGF in Equation (5.10) is further used to evaluate channel capacity under various adaptive schemes.

### 5.4 Marginal MGF Based Channel Capacity Analysis

#### 5.4.1 Optimal Rate Adaptation

When the transmitter power remains constant, usually as a result of channel state information being available at receiver side, the channel capacity with optimal rate adaptation (CORA) in terms of the MGF based approach can be expressed as [157]:

\[ C_{ORA} = \frac{1}{\ln(2)} \int_{0}^{\infty} E_{i}(-s) M_{\gamma}^{(1)}(s) \, ds \] (5.11)

where \( E_{i}(\cdot) \) denotes the exponential integral function as defined in [156] and \( M_{\gamma}^{(1)}(s) \) is the first derivative of the MGF. The integral in Equation (5.11) is called \( E_{i} \)-transform, as \( E_{i}(\cdot) \) kernel function defines this integral transform. Moreover, in those scenarios where very complicated expressions of the MGF of the received SNR do not allow easily computing the aforementioned integral in closed form, the result in the Equation (5.11) can efficiently and easily obtained by using standard computing
environments, such as MAPLE and Wolfram MATHEMATICA. By differentiating Equation (5.8) with respect to \( s \) we get

\[
M^1(s) = -\frac{A}{D} \Gamma(Mm) \times \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m)} \frac{1}{k!} (c)^k \frac{(Mm + k)}{(B + s)^{Mm+k+1}} \tag{5.12}
\]

By putting the value of \( M^1(s) \) in Equation (5.11) we get,

\[
C_{ORA} = -\frac{1}{\ln(2)} \frac{A}{D} \Gamma(Mm) \times \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m)} \frac{(Mm + k)}{k!} (c)^k I_2
\tag{5.13}
\]

where

\[
I_2 = \int_0^\infty \frac{1}{(B + s)^{Mm+k+1}} ds - \int_0^\infty \frac{1}{(B)^{Mm+k+1}} \left\{ \frac{1}{1 + \frac{B}{s}} \right\}^{Mm+k+1} ds
\tag{5.14}
\]

By putting \( \frac{s}{B} = t \) in Equation (5.14), and after some mathematical manipulation, we get:

\[
I_2 = \frac{1}{(B)^{Mm+k}} \int_0^\infty \frac{E_t(Bt)}{(1 + t)^{Mm+k+1}} dt
\tag{5.15}
\]

From [157 Equation (8.4.2.7)] along with [157 Equation (8.4.11.1)], Equation (5.15) can be expressed as:

\[
I_2 = \frac{1}{(B)^{Mm+k}} \int_0^\infty \left[ \frac{1}{1 + t} \right]^{-(k + Mm + 1)} \left[ \begin{array}{c|c}
1 & 1 \\
1 & 0
\end{array} \right] dt
\tag{5.16}
\]

From [157 Equation (2.24.1)], Equation (5.16) can be expressed as:

\[
I_2 = \frac{G^3}{2} \left[ \begin{array}{c|c}
B & 0 \\
0 & (k + Mm)
\end{array} \right]
\tag{5.17}
\]

By putting value of \( I_2 \) from Equation (5.17) to Equation (5.13), we get:

\[
C_{ORA} = \frac{1}{\ln(2)} \frac{A}{D} \Gamma(Mm) \times \sum_{k=0}^{\infty} \frac{\Gamma(k + m)}{\Gamma(m)} \frac{(Mm + k)}{k!} (c)^k \frac{G^3}{2} \left[ \begin{array}{c|c}
B & 0 \\
0 & (k + Mm)
\end{array} \right]
\tag{5.18}
\]
where \( G(\bullet) \) is Meijer’s G function [149 Equation (9.301)]. Expression of \( C_{\text{ORA}} \) in Equation (5.18) shows summation of infinite series but it diverges rapidly with the increase of number of terms and only few terms are required to get closed form expression of \( C_{\text{ORA}} \).

5.4.2 Optimal simultaneous power and rate adaptation

When both the transmitter and receiver having perfect channel information, then the channel capacity for optimal rate adaptation (\( C_{\text{OPRA}} \)) is given by [107]:

\[
C_{\text{OPRA}} = B \int_0^\infty \log_2 \left( \frac{\gamma}{\gamma_o} \right) f_\gamma(\gamma) d\gamma
\]

(5.19)

where \( B \) is the channel bandwidth (in Hz) and \( \gamma_o \) is optimal cut off SNR level below which no transmission takes place. This optimal cutoff must satisfy

\[
\int_{\gamma_o}^\infty \left( \frac{1}{\gamma} - \frac{1}{\gamma_o} \right) f_\gamma(\gamma) d\gamma = 1
\]

(5.20)

to achieve the channel capacity by Equation (5.19), the amount of fading must be tracked at the transmitter and receiver both, transmitter adapts its power and data rate to the channel variations by allocating high-power levels and rates for good channel condition and low power levels and rates for bad channel condition [107]. Furthermore, this optimal policy suffers a probability of outage \( P_{\text{out}} \), equal to probability of no transmission, given by:

\[
P_{\text{out}} = \int_0^{\gamma_o} f_\gamma(\gamma) d\gamma
\]

(5.21)

Now, an alternate method to evaluate the \( C_{\text{OPRA}} \) by using the marginal MGF is discussed below. By substituting first substituting \( \gamma = q + \gamma_o \) in the Equation (5.19) and then again substituting \( q/\gamma_o = x \) in Equation (5.19), the equation (5.19) is reduces to:

\[
C_{\text{OPRA}} = \frac{\gamma_o}{\ln(2)} \int_0^\infty \ln(1 + x) f_\gamma(\gamma_o(1 + x)) dx = \frac{\gamma_o}{\ln(2)} \bar{E}(\ln(1 + \gamma); \gamma_o)
\]

(5.22)

Form [112 Equation (6)] by using
\[\ln(1+x) = \int_0^\infty \left( 1 - e^{-xz} \right) e^{-z} \, dz \]  \hspace{1cm} (5.23)

From (5.27) and (5.28), we get:

\[ C_{\text{OPRA}} = \frac{\gamma}{\ln(2)} \int_0^\infty \left[ \frac{1}{z} \right] e^{-x} f_x(x) \, dx \]  \hspace{1cm} (5.24)

where \( E[e^{-x} \gamma_0] = \int_0^\infty e^{-x} f_x(\gamma_0(1+x)) \, dx \)

\[ I_3 = \int_0^\infty e^{-x} f_x(\gamma_0(1+x)) \, dx \]  \hspace{1cm} (5.25)

By putting \( \gamma_0(1+x) = g \) in Equation (5.25) and after some mathematical manipulation, the integral \( I_3 \) in Equation (5.25) can be expressed as:

\[ I_3 = \frac{e^{-x}}{\gamma_0} \int_0^\infty e^{-x} f_x(g) \, dg = \frac{e^{-x}}{\gamma_0} M\left( \frac{z}{\gamma_0}, \gamma_0 \right) \]  \hspace{1cm} (5.26)

where \( M\left( \frac{z}{\gamma_0}, \gamma_0 \right) \) is a marginal MGF as given by Equation (5.2). By putting value of \( I_3 \) from Equation (5.26) to Equation (5.24), we get:

\[ C_{\text{OPRA}} = \frac{\gamma}{\ln(2)} \left[ \int_0^\infty \frac{e^{-x}}{\gamma_0} \frac{1}{\gamma_0} M\left( \frac{z}{\gamma_0}, \gamma_0 \right) \right] \, dz \]  \hspace{1cm} (5.27)

For evaluation of \( C_{\text{OPRA}} \) in Equation (5.27), first integral and second integral can be evaluated numerically by using standard software like Maple and Mathematica. To obtain the optimal cut-off SNR \( \gamma_c \) in Equation (5.27), we need to solve the Equation (5.20), by using standard techniques as given in [107, 153]. Here, we are presenting MMGF based approach for optimization of cut-off SNR \( \gamma_c \). By re-arranging the Equation (5.20), we get:

\[ \frac{1}{\gamma} \int_{\gamma_c}^{\gamma} f_x(\gamma) \, d\gamma - \frac{1}{\gamma} \int_{\gamma_c}^{\gamma} f_x(\gamma) \, d\gamma = 1 \]  \hspace{1cm} (5.28)
\[ I_4 = \frac{1}{\gamma_a} \int_{\gamma_0}^{\gamma_a} \int_{x_0}^{x} f_\gamma(\gamma) d\gamma \]  \hspace{1cm} (5.29)

\[ I_5 = \int_{\gamma_0}^{\gamma_a} \int_{x_0}^{x} f_\gamma(\gamma) d\gamma \]  \hspace{1cm} (5.30)

By substituting \( s = 0 \) and \( a = \gamma_a \) in Equation (5.2), we get:

\[ \hat{M}(0, \gamma_a) = \int_{\gamma_0}^{\infty} f_\gamma(\gamma) d\gamma \]  \hspace{1cm} (5.31)

From Equation (5.29) and Equation (5.31), \( I_4 \) can be expressed as:

\[ I_4 = \frac{\hat{M}(0, \gamma_a)}{\gamma_a} \]  \hspace{1cm} (5.32)

By replacing \( \frac{1}{\gamma} = \int_{0}^{\infty} e^{-\gamma s} ds \) in the Equation (5.30) and by the changing the order of integration, we get:

\[ I_5 = \int_{0}^{\infty} e^{-xt} \int_{x_0}^{x} f_\gamma(x) dx \int_{0}^{\infty} \hat{M}(s, \gamma_a) ds = \int_{0}^{\infty} \hat{M}(s, \gamma_a) ds \]  \hspace{1cm} (5.33)

By substituting \( I_4 \) and \( I_5 \) in Equation (5.28), we get:

\[ \frac{\hat{M}(0, \gamma_a)}{\gamma_a} - \int_{0}^{\infty} \hat{M}(s, \gamma_a) ds = 1 \]  \hspace{1cm} (5.34)

where \( \hat{M}(s, \gamma_a) \) is the MMGF as given in Equation (5.2). From Equation (5.33) and Equation (5.7), Integral \( I_5 \) is evaluated as given below:

\[ I_5 = \frac{A}{D} \sum_{k=0}^{\infty} \frac{\Gamma(k + m \alpha \Gamma(m \gamma_a)) (C)^k}{k!} I_6 \]  \hspace{1cm} (5.35)

\[ I_6 = \int_{0}^{\infty} \Gamma(k + m \gamma_a, (B + s)) (B + s)^{(k - m \gamma_a)} ds \]  \hspace{1cm} (5.36)

By substituting \( B + s = t \) in the Equation (5.36) and after simplification, we get:

\[ I_6 = \int_{0}^{\infty} \Gamma(k + m \gamma_a, t) (t)^{(k - m \gamma_a)} dt \]  \hspace{1cm} (5.37)

From [157 Equation (8.4.16.2)], the Equation (5.37) can be expressed as:
\[ I_6 = \frac{\gamma_s}{\gamma_s} \left( t - (k + mM) \right) G \begin{bmatrix} 2 & 0 \\ 1 & 0 \\ \gamma_s & 1 \end{bmatrix} G \begin{bmatrix} 2 & 0 \\ 3 & 0 \\ (k + mM) & 1 \end{bmatrix} dt \] (5.38)

From [157 Equation (2.24.2.3)], the Equation (5.38) can be expressed as:

\[ I_6 = \left( B + (k + mM) \right) \frac{G^3}{G^3} \begin{bmatrix} B \gamma_s & 1 \\ 3 & (k + mM) - 1 \end{bmatrix} \] (5.39)

By putting result of \( I_6 \) from the Equation (5.39) in Equation (5.35), we get:

\[ I_5 = \frac{A}{D} \sum_{k=0}^{k} \frac{\Gamma(k + m) \Gamma(M)}{\Gamma(k + M + m)} \frac{(C)^k}{k!} \frac{1}{(B)^{(k + mM) - 1}} \] (5.40)

From Equation (5.2) Integral \( I_4 \) can be expressed as:

\[ I_4 = \frac{\hat{M}(0, \gamma_s, \gamma_s)}{\gamma_s} = \frac{A}{\gamma_s D} \sum_{k=0}^{k} \frac{\Gamma(k + m) \Gamma(M)}{\Gamma(k + M + m)} \frac{(C)^k}{k!} \frac{\Gamma(k + mM, \gamma_s)}{\Gamma(k + M)} \] (5.41)

By substituting results of Equation (5.40) and (5.41) in Equation (5.34), we get:

\[ \left[ \frac{A}{\gamma_s D} \sum_{k=0}^{k} \frac{\Gamma(k + m) \Gamma(M)}{\Gamma(k + M + m)} \frac{(C)^k}{k!} \frac{1}{(B)^{(k + mM) - 1}} \right] \left[ \frac{A}{D} \sum_{k=0}^{k} \frac{\Gamma(k + m) \Gamma(M)}{\Gamma(k + M) \Gamma(k + mM)} \frac{(C)^k}{k!} \right] = 1 \] (5.42)

Although, the optimal cut-off SNR \( \gamma_s \) cannot be obtained in close-form in Equation (5.42), so numerical evaluation is performed in order to get optimal cut-off SNR \( \gamma_s \).

**5.4.3 CHANNEL INVERSION WITH FIXED RATE**

The channel capacity for channel inversion with fixed rate (CIFR) requires that the transmitter exploits the channel state information so that constant SNR is maintained at receiver. As this method inverts the channel fading at receiver therefore it provides a fixed transmission rate. The channel capacity with fixed channel inversion rate can be expressed as [107]:
\[ C_{CIFR} = \log_2 \left( 1 + \frac{1}{\int_0^\infty \frac{f_\gamma(\gamma)}{\gamma} d\gamma} \right) \]  

The Equation (5.43) can be expressed in the term of the MGF as:

\[ I_7 = \int_0^\infty \frac{f_\gamma(\gamma)}{\gamma} d\gamma \]  

By replacing \( \frac{1}{\gamma} = \int_0^\infty e^{-\gamma s} ds \) in Equation (5.44), we get:

\[ I_7 = \int_0^\infty f_\gamma(\gamma) \left( \int_0^\infty e^{-\gamma s} ds \right) d\gamma \]  

By changing the order of integration in Equation (5.45), we get:

\[ I_7 = \int \left( \int_0^\infty f_\gamma(\gamma)e^{-\gamma s} d\gamma \right) ds \]

So now

\[ I_7 = \int_0^\infty M(s) ds \]  

By putting the value of \( I_4 \) from the Equation (5.46) in Equation (5.43), we get:

\[ C_{CIFR} = \log_2 \left( 1 + \frac{1}{\int_0^\infty M(s) ds} \right) \]

By putting the value of \( M(s) \) from Equation (5.10) to Equation (5.47), we get:

\[ I_7 = \int_0^\infty \left( 1 + \frac{\tilde{\gamma}_i(1 - \rho + M\rho)s}{m} \right) \left( 1 + \frac{\tilde{\gamma}_i(1 - \rho)s}{m} \right)^{-m(M-1)} ds \]

By using [149 Equation (3.259.3)], Integral \( I_7 \) in Equation (5.47) can be expressed as:

\[ I_7 = \frac{mB(1, m(M - 1))}{(1 + \rho(M - 1))\tilde{\gamma}_i} \binom{m(M - 1), 1, mM + \frac{M\rho}{1 + \rho(M - 1)}}{\binom{M\rho}{1 + \rho(M - 1)}} \]  

By putting the result in (5.49) in Equation (5.47), we get:
\[ C_{\text{CFR}} = \log_2 \left( 1 + \frac{(1 + \rho(M - 1))F_r}{mB(1, mM - 1) \frac{1}{\gamma_0} \int_{\gamma_0}^{\infty} \left( \frac{M\rho}{1 + \rho(M - 1)} \right) d\gamma} \right) \]  

(5.50)

where B(\bullet) is beta function [149 Equation (8.384.1)]. The above expression evaluates accurate value of channel capacity for channel inversion with fixed rate scheme for arbitrary value of fading parameter.

5.4.4 TRUNCATED CHANNEL INVERSION

The CIFR suffers from a large capacity penalty relative to the other techniques. The truncated CIFR is better approach than CIFR, where channel fading is inverted above a cut-off SNR (\( \gamma_0 \)). The capacity for truncated CIFR is defined as [107]:

\[ C_{\text{TCIFR}} = \log_2 \left( 1 + \frac{1}{\int_{\gamma_0}^{\infty} \frac{f_\gamma(\gamma)}{\gamma} d\gamma} (1 - P_{\text{out}}) \right) \]  

(5.51)

In the Equation (5.51), integral \( \int_{\gamma_0}^{\infty} \frac{f_\gamma(\gamma)}{\gamma} d\gamma \) is similar with integral \( I_3 \) in the Equation (5.30) and it can be written in term of MMGF as given in Equation (5.33). The outage probability \( P_{\text{out}}(\gamma_0) \) in Equation (5.21) can be rewritten as:

\[ P_{\text{out}}(\gamma_0) = 1 - \int_{\gamma_0}^{\infty} f_\gamma(\gamma) d\gamma \]  

(5.51)

From Equation (5.31), the Equation (5.51) can be expressed as:

\[ P_{\text{out}}(\gamma_0) = 1 - \hat{M}(0, \gamma_0) \]  

(5.52)

By putting \( a = \gamma_0 \) and \( s = 0 \) in Equation (5.12), \( P_{\text{out}}(\gamma_0) \) can be expressed as:

\[ P_{\text{out}}(\gamma_0) = 1 - \frac{A}{D} \sum_{k=0}^{\infty} \frac{\Gamma(k + m)\Gamma(Mm)}{\Gamma(m)\Gamma(k + Mm)} \frac{(C)^k}{k!} \frac{\Gamma(k + mM, \gamma_0B)}{(B)^{k+mM}} \]  

(5.53)

\[ C_{\text{TCIFR}} = \log_2 \left( 1 + \frac{1}{\int_{0}^{\infty} \hat{M}(t, \gamma_0) dt} \right) \{\hat{M}(0, \gamma_0)\} \]  

(5.54)
By substituting the result of $I_s$ from the Equation (5.40) and $P_{end}$, in Equation (5.54), we get:

$$C_{TCFR} = \log_2 \left( 1 + \frac{1}{\frac{A}{D} \frac{\Gamma(k+m)\Gamma(k+M)}{\Gamma(m)\Gamma(k+M+m)} \frac{G^3}{2} \frac{B}{Y} \frac{1}{(k+mM-1)} \frac{0}{(k+mM)}^{k+mM-1} \right)$$

By using Equation (5.55), the channel capacity for truncated CIFR scheme can be evaluated easily for arbitrary value of fading parameter.

### 5.5 RESULT AND DISCUSSION

In this section, we have presented numerical results for the channel capacity with MRC diversity over correlated Nakagami-$m$ fading channel. Figure 5.2 shows the channel capacity with optimal rate adaptation ($C_{ORA}$) versus SNR for various diversity receivers. As the number of diversity receiver increases, $C_{ORA}$ improves significantly. Figure 5.3 shows the effect of correlation coefficient on the channel capacity for optimal rate adaptation ($C_{ORA}$).

![Figure 5.2](image)

**Figure 5.2** The channel capacity with optimal rate adaptation ($C_{ORA}$) versus SNR for various diversity receivers.
As the correlation coefficient increases, $C_{\text{ORA}}$ decreases. Figure 5.4 depicts the channel capacity for optimal simultaneous power and rate adaptation ($C_{\text{OPRA}}$) versus SNR for various diversity receivers. As the number of diversity receivers increases, $C_{\text{OPRA}}$ improves, similarly as in Figure 5.2.

**Figure 5.3** The channel capacity with optimal rate adaptation ($C_{\text{ORA}}$) versus SNR for several correlation coefficients.

**Figure 5.4** The channel capacity for optimal rate adaptation ($C_{\text{OPRA}}$) versus SNR for various diversity receivers.
Figure 5.5 shows the channel capacity for $C_{OPRA}$ versus SNR for several correlation coefficients, similarly as in Figure 5.3. Figure 5.6 shows the characteristics of channel inversion with fixed rate ($C_{CIFR}$) versus SNR for various diversity receivers, in this $C_{CIFR}$ improves with the increase of diversity receiver.

![Graph](image)

**Figure 5.5** The channel capacity for optimal rate adaptation ($C_{OPRA}$) versus SNR for several of correlation coefficients.

![Graph](image)

**Figure 5.6** The channel inversion with fixed rate ($C_{CIFR}$) versus SNR for various diversity receivers.
Figure 5.7 The channel inversion with fixed rate (CIFR) versus SNR for various correlation coefficients.

Figure 5.8 The channel capacity with truncated channel inversion ($C_{TCIFR}$) versus cut-off SNR ($\gamma_0$) for various value of SNR.

Figure 5.7 shows effect of correlation coefficient on channel inversion with fixed rate (CIFR) versus SNR, as correlation coefficients increases, $C_{CIFR}$ decreases but decrement is less in comparison to that as shown in Figure 5.3 and Figure 5.5. Figure 5.8 shows the characteristics of channel capacity with truncated channel inversion ($C_{TCIFR}$) with cut-off SNR ($\gamma_0$) for various values of SNR. From Figure 5.8 it is clear that as SNR increase, the cut-off rate ($\gamma_0$) also increases. Figure 5.9 shows the channel
capacity with truncated channel inversion ($C_{TCIFR}$) versus MRC diversity, as the MRC diversity increases, the cut-off rate ($\gamma_0$) increases significantly.

**Figure 5.9** The channel capacity with truncated channel inversion ($C_{TCIFR}$) versus MRC diversity.

![Figure 5.9](image)

**Figure 5.10** The channel capacity with truncated channel inversion ($C_{TCIFR}$) versus cut-off SNR ($\gamma_0$) for the various values of correlation coefficient.

![Figure 5.10](image)
Figure 5.11 Comparison of the channel capacity with optimal rate adaptation (CORA) versus correlation coefficient for diversity $M = 3$ for different values of SNR.

Figure 5.10 depicts the channel capacity with truncated channel inversion (C_TCFR) with cut-off SNR ($\gamma_c$) for various values of correlation coefficient. As the correlation coefficient increases, the cut-off rate decreases slowly. Figure 5.11 to Figure 5.14 shows the comparison of channel capacity under various adaptive condition with the reported literature [153] for correlated Rayleigh fading channel ($m = 1$). The result of the proposed method is similar with that of [153].

Figure 5.12 Comparison of channel capacity for the optimal simultaneous power and rate adaptation (CОРРА) versus SNR for various correlation coefficients of the proposed method with [153].
Figure 5.13 Comparison of the channel capacity of channel inversion with fixed rate (CIFR) versus SNR for various correlation coefficients of the proposed method with [153].

In the Figure 5.11, the characteristic of the channel capacity for optimal rate adaptation with correlation coefficients of the proposed method has been compared with [153] by considering the Rayleigh fading channel \((m = 1)\). The results of the proposed method are comparable with that of the [153]. In Figure 5.12 shows the comparison of the characteristics of channel capacity for optimal simultaneous power and rate adaptation with SNR for various correlation coefficients of the proposed method with [153] by considering the Rayleigh fading channel \((m = 1)\).

The results of the proposed method are comparable with that of the [153]. In Figure 5.13 depicts the comparison of the characteristics of channel capacity of channel inversion with fixed rate with SNR for various correlation coefficients of the proposed method with [153] by considering the Rayleigh fading channel \((m = 1)\). The results of the proposed method are comparable with that of the [153].

In Figure 5.14 explore the comparison of the characteristics of channel capacity of channel inversion with truncated channel inversion \((C_{TCIFR})\) versus cut-off SNR \((\gamma_0)\) for various correlation coefficients of the proposed method with [153] by considering the Rayleigh fading channel \((m = 1)\). The results of the proposed method are comparable with that of the [153].
Figure 5.14 The channel capacity with truncated channel inversion \( C_{TChR} \) versus cut-off SNR \( \gamma_0 \) for various correlation coefficients of the proposed method with [153].

5.5 CONCLUSION

In this Chapter, we have obtained the marginal MGF for correlated Nakagami-\( m \) fading channel with MRC diversity. The obtained expression for marginal MGF function is used to evaluate the channel capacity under different adaptation policies. We have obtained the novel expression for various channel capacities for arbitrary value of \( m \). We have also analyzed the effect of correlation coefficients on channel capacity. Due to the simple forms, these results offer a useful analytical tool for the accurate performance evaluation of various communication systems of practical interest.