

# A Generalized Approach on Outage Performance Analysis of Dual-Hop Decode and Forward Relaying for 5G and Beyond Scenarios

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## Research Article

**Keywords:** outage performance, decode and forward, 5G communication, generalized fading

**Posted Date:** June 17th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-482459/v1>

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# A Generalized Approach on Outage Performance Analysis of Dual-Hop Decode and Forward Relaying for 5G and Beyond Scenarios

Daljeet Singh

**Abstract** This paper presents a generalized approach of performance analysis of relay aided communication system for 5G and beyond scenarios. A dual-hop decode and forwarding scheme is considered in the analysis. The relationship between the outage performance and cumulative distribution function (CDF) of signal to noise ratio (SNR) is exploited to derive a universal expression of outage probability valid for all fading scenarios irrespective of their nature or complexity. Further, an effort is made to parameterise the channel PDF in such a manner that reflects a commonly encountered practical fading scenario faced by current and future wireless communication systems. The analytical results obtained for various cases are validated by Monte-Carlo simulations.

**Keywords** outage performance · decode and forward · 5G communication · generalized fading

## 1 Introduction

Dual-hop relaying is a special case of relay-aided communication technology in which information is transferred from source to destination via an intermediary relay station over two hops. Dual hop relaying is commonly deployed in user cooperation diversity schemes. User cooperation diversity schemes help improve communication system coverage, reliability, capacity, spectral efficiency and power efficiency [1,2]. Dual hop relaying is expected to become a popular solution for many 5G and beyond systems which require the provision of high data rate and reliable communication with good spectral and power

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efficiency. Dual hop relaying is already being deployed in many popular wireless communication standards like IEEE 802.16j/m and 3GPP LTE-Advanced [3] and is used in many communication systems like wireless sensor networks (WSN) and cellular communication systems. Dual-hop relaying technology having being considered as a key technology for 5G scenarios and beyond by the METIS project [4]. Therefore, its performance analysis ought to be conducted considering channel characteristics that are to be encountered in 5G systems and beyond. The propagation scenarios in 5G systems are so diverse and include vehicular and machine-to-machine communication, communication in the Internet of Things (IoT) systems, remote set-ups and urban scenarios with high-density crowd. In addition to the propagation scenario, channel characteristic is also influenced by other factors such as transmission equipment (smart antennas), transmission frequency (mm-wave transmission) and mobility of communicating devices. 5G channel characteristics being so diverse and peculiar, conventional statistical distributions like Rayleigh, Rician etc. fail to accurately characterize most channels scenarios. There is, therefore, the need to study the performance of any technology to be used in 5G systems and beyond using other more appropriate and versatile statistical distributions whose parameters can be modified to accurately represent a wide range of fading encountered [4].

Various channel models are introduced in the literature for analysing the performance of relaying systems in 5G scenarios. These generalized fading models can be categorized into small scale multipath scattering propagation models like Rayleigh [5], Rician, Nakagami-m [6], Weibull [7], Nakagami-q [8],  $\eta - \lambda - \mu$  [9],  $\alpha - \lambda - \mu$  [10],  $\kappa - \mu$  [11],  $\alpha - \mu$ , and  $\eta - \mu$  fading, composite multipath shadowing Line of Sight (LOS) propagation (composite small and large scale fading) models like generalized Gamma [12] and generalized K [13] fading, composite multipath scattering and shadowing propagation with LOS like Fluctuating Two Ray (FTR) fading [14].

To date, a number of studies have been performed on the performance analysis of relay aided wireless communication systems [11, 15–21]. Authors in [15] have derived the expression of outage probability of dual-hop DF relaying over Rayleigh-Generalized gamma fading channel. In [16], a dual-hop system is analysed for mixed  $\eta - \mu$  and gamma-gamma fading. The symbol error rate (SER) performance of amplify-and-forward (AF) scheme over asymmetric fading channels is presented in [17]. In [11], the expression for SER, outage probability and outage capacity of DF relaying over  $\eta - \mu$  and  $\kappa - \mu$  fading are derived. Dixit and Sahu in [18] calculated the SER and outage of dual-hop DF relaying over Rice fading.

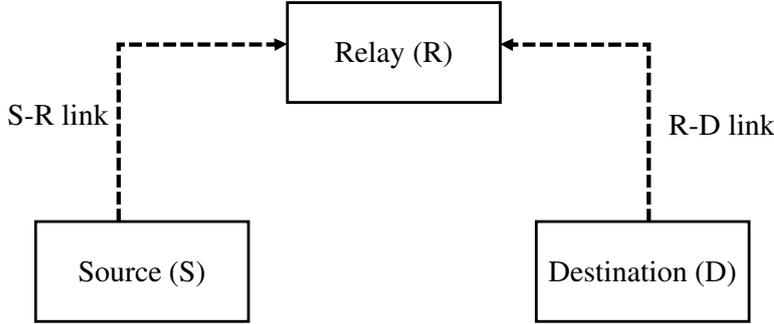
The performance of single-branch single-relay AF relaying system over mixed Rayleigh-Nakagami-m fading is analysed by Benmahmoud in [19]. Kapucu in [20] analysed the performance of dual branch selection combining scheme over  $\alpha - \kappa - \mu$  fading. The bit error rate (BER) expression for M-ary phase-shift keying industrial cooperative relaying system is derived over Generalized-K composite fading channels by Marjanovic et al. [21].

Upon a thorough analysis of literature, it is observed that most of the studies on performance analysis of relay aided communication system assume a fixed and static fading scenario for the wireless link between source-relay and relay-destination. In 5G scenarios, this condition is not always met. Therefore, there is a need for a generalized framework for the performance analysis of relay aided communication which suits these circumstances. In this paper, a universal framework is developed for the outage performance analysis of relay aided communication system for 5G and beyond scenarios. For this task, the dual-hop decode and forwarding (DF) scheme is considered. The relationship between the outage performance and cumulative distribution function (CDF) of signal to noise ratio (SNR) is exploited to derive a universal expression of outage probability valid for all fading scenarios irrespective of their nature or complexity. Further, to illustrate the calculation of outage probability using the derived expression, the outage probability for four different scenarios are discussed. To the best of author's knowledge, no such framework is available in the literature to cater to all possible fading scenarios. The analytical results obtained for various cases are validated by Monte-Carlo simulations. The rest of the paper is structured as follows: the system model is explained in Section 2 and the generalized outage probability expression is derived in Section 3. Section 4 illustrates the calculation of outage probability for various test cases. The results and discussion are given in Section 5 and Section 6 holds the concluding remarks.

## 2 System Model

The system model consists of a source (S), a destination (D) and one relay (R). Communication between S and D is achieved with the aid of relay node operating in a half-duplex mode which employs a DF based algorithm. It is assumed that S, D and R have a single antenna for transmission and reception. The power spectral density (PSD) of additive white Gaussian noise (AWGN) at the receiver is assumed to be  $N_0$  with zero mean,  $n \sim CN(0, N_0)$ . The system model is shown in Fig. 1.

Let the instantaneous SNR between S-R and R-D be  $\gamma_{SR}$  and  $\gamma_{RD}$  respectively defined as  $\gamma_{SR} = \frac{|h_{SR}|^2 P_{SR}}{N_0}$  and  $\gamma_{RD} = \frac{|h_{RD}|^2 P_{RD}}{N_0}$ ; where  $h_{SR}$  and  $h_{RD}$  are the channel coefficients between source-relay and relay-destination link.  $P_{SR}$  and  $P_{RD}$  are the power transmitted by source and relay respectively. Further, let the PDF of  $\gamma_{SR}$  and  $\gamma_{RD}$  be  $p_{\gamma_{SR}}(\gamma_{SR})$  and  $p_{\gamma_{RD}}(\gamma_{RD})$  respectively. In order to support the unified approach of this study, it is assumed that the fading channel between S-R and R-D can belong to any family of PDF. Further, it is also assumed that  $p_{\gamma_{SR}}(\gamma_{SR})$  and  $p_{\gamma_{RD}}(\gamma_{RD})$  can acquire different fading envelopes. Furthermore,  $p_{\gamma_{SR}}(\gamma_{SR})$  and  $p_{\gamma_{RD}}(\gamma_{RD})$  are assumed to be independent non-identical distributed (INID).



**Fig. 1** System model of DF relaying

### 3 Generalized Outage Probability Expression

The condition of outage ensues when either  $\gamma_{SR}$  or  $\gamma_{RD}$  or both fall below a certain specific threshold  $\gamma_{th}$ . Therefore, the outage probability  $p_{out}(\gamma_{th})$  for a dual hop DF relay-based system can be calculated as [15]

$$p_{out}(\gamma_{th}) = p(\gamma_1 \leq \gamma_{th}) \| p(\gamma_2 \leq \gamma_{th}) \quad (1)$$

After some mathematical manipulations, (1) can be simplified as

$$p_{out}(\gamma_{th}) = p(\min(\gamma_1, \gamma_2) \leq \gamma_{th}) \quad (2)$$

Now, using the relation  $(p(\gamma_1) \leq \gamma_{th}) + (p(\gamma_1) > \gamma_{th}) = 1$ ,  $p_{out}(\gamma_{th})$  in (2) can be rewritten as

$$p_{out}(\gamma_{th}) = 1 - p(\gamma_1 > \gamma_{th})p(\gamma_2 > \gamma_{th}) \quad (3)$$

Representing  $p(\gamma_1 > \gamma_{th})$  in the integral form leads to

$$p_{out}(\gamma_{th}) = 1 - \int_{\gamma_{th}}^{\infty} p_{\gamma_1}(\gamma_1) d\gamma_1 \int_{\gamma_{th}}^{\infty} p_{\gamma_2}(\gamma_2) d\gamma_2 \quad (4)$$

Using the definition of CDF of a random variable, (4) can be simplified as

$$p_{out}(\gamma_{th}) = 1 - p_{\gamma_1}(\gamma_{th})p_{\gamma_2}(\gamma_{th}) \quad (5)$$

where  $p_{\gamma_1}(\gamma_{th})$  and  $p_{\gamma_2}(\gamma_{th})$  are the complementary cumulative distribution functions (CCDF) of  $p_{\gamma_1}(\gamma_1)$  and  $p_{\gamma_2}(\gamma_2)$  evaluated at  $\gamma_{th}$ . Using (5), the outage probability of a DF aided relay communication system can be calculated for any fading scenario using the CDF of SNR of the fading channel. In order to illustrate the calculation of outage probability using (5), some cases involving different fading scenarios are explained in Section 4.

**Table 1** CDF of some popular fading channels

Sr. no.	Fading channel	CDF Evaluated at and from $\gamma_{th}$
Small scale multipath scattering propagation models		
1	Rayleigh [5]	$1 - \exp\left(\frac{-\gamma_{th}}{\gamma}\right)$
2	$\eta - \lambda - \mu$ [9]	$\left[ 1 - \left( \frac{2\sqrt{\eta(1+\lambda^2)}b}{r^2} \right)^{2\mu} \frac{\sqrt{\pi}}{\gamma(u)\epsilon^{2\mu}d^{\mu-0.5}} \sum_{j=0}^{\infty} \frac{1}{j!\Gamma(0.5+\mu+j)} \left( \frac{d}{2\epsilon} \right) \left( \Gamma(2(\mu+j)) - \Gamma\left(2(\mu+j), \frac{\epsilon\gamma_{th}}{\gamma}\right) \right) \right]$
3	$\alpha - \lambda - \mu$ [10]	$\frac{\sqrt{\pi}(1-\lambda^2)^\mu}{2^{2\mu-1}\Gamma(\mu)} \sum_{j=0}^{\infty} \frac{\left(\frac{d}{2\epsilon}\right)^{2j}}{j!\Gamma(j+\mu+0.5)} \left( \Gamma(2(\mu+j)) - \Gamma(\mu+2j, b) \right), 0.5cm\hat{b} = \frac{2\mu}{1-\lambda^2} \gamma_{th}^\alpha$
4	Nakagami-m [6]	$1 - \frac{\Gamma\left(m, \frac{m}{\gamma} \gamma_{th}\right)}{\Gamma(m)}$
5	Weibull [7]	$1 - \exp\left(-\frac{\gamma_{th}}{\gamma} \Gamma\left(1 + \frac{2}{c}\right)^{\frac{c}{2}}\right)$
6	Nakagami-q [8]	$1 - \left[ Q\left(\alpha(q)\sqrt{\frac{\gamma_{th}}{4\gamma}}, \beta(q)\sqrt{\frac{\gamma_{th}}{4\gamma}}\right) - Q\left(\beta(q)\sqrt{\frac{\gamma_{th}}{4\gamma}}, \alpha(q)\sqrt{\frac{\gamma_{th}}{4\gamma}}\right) \right]$
Composite Multipath-Shadowing-LOS propagation (composite small and large scale fading)		
7	Generalized Gamma [4]	$1 - \frac{\Gamma(m, \beta^v \gamma_{th}^v)}{\Gamma(m)}$
8	Generalized K [13]	$1 - \left[ \pi \operatorname{csc}(\pi\alpha) \left( \frac{(\Xi\gamma_{th})^m {}_2F_2(m; 1-\alpha; 1+m; \Xi\gamma_{th})}{\Gamma(k)\Gamma(1-\alpha)\Gamma(1+m)} - \frac{(\Xi\gamma_{th})^m {}_1F_2(k; 1+\alpha; 1+k; \Xi\gamma_{th})}{\Gamma(m)\Gamma(1+\alpha)\Gamma(1+k)} \right) \right]$
Composite multipath scattering and shadowing propagation with LOS component		
9	FTR [14]	$1 - \left[ \frac{1}{2^{m-1}} \frac{1+K}{\gamma} \left( \frac{m}{\sqrt{(m+K)^2 - K^2 \Delta^2}} \right)^m \sum_{q=0}^{\lfloor \frac{m-1}{2} \rfloor} (-1)^q C_q^{m-1} \left( \frac{m+K}{\sqrt{(m+K)^2 - K^2 \Delta^2}} \right)^{m-1-2q} \gamma_{th} \phi_2^{(4)} \left( 1+2q-m, m-q-0.5; -\frac{m(1+K)}{(m+K)\gamma} \gamma_{th}, -\frac{m(1+K)}{(m+K(1+\Delta))\gamma} \gamma_{th}, -\frac{m(1+K)}{(m+K(1-\Delta))\gamma} \gamma_{th}, -\frac{1+K}{\gamma} \gamma_{th} \right) \right]$

#### 4 Calculation of Outage Probability using (5)

In this section, the use of derived outage probability expression (5) is demonstrated using various scenarios as follows:

**Scenario 1:** Let the fading envelopes of the two links take Rayleigh and Generalised Gamma PDF. The Generalised Gamma distribution generalises frequent used models for multipath, shadowing and composite fading and contains Nakagami, Rayleigh and Weibull distributions as special cases and log-normal distribution as a limiting case [15].

Rayleigh-Generalised Gamma fading scenario models a scenario in which one link represented by Rayleigh fading is subjected to intense scattering with no line of sight of transmission and the other hop represented by Generalised Gamma fading can experience any of multipath fading, shadowing or a composite fading at any time. The Rayleigh fading model also applies to the propagation of reflected and refracted paths through the troposphere and ionosphere and to ship-to-ship radio links. Using the expressions of CDF from Table 1 in (5), the outage probability for scenario 1 can be calculated as

$$p_{out}(\gamma_{th}) = 1 - \exp\left(\frac{-\gamma_{th}}{\gamma}\right) \frac{\Gamma(m, \beta^v \gamma_{th}^v)}{\Gamma(m)} \quad (6)$$

**Scenario 2:** For this case, let the two links take Nakagami-m PDF and Weibull PDF respectively. Nakagami-m is a versatile generalised multipath fading distribution that is capable of modelling fading scenarios that are more severe than Rayleigh fading ( $m < 1$ ). Nakagami-m contains Rayleigh, One-sided Gaussian as special cases and AWGN as a limiting case [19] and it can be easily matched to equivalent Rice distribution [18]. Weibull fading has proven to produce a good fit to experimental data in multipath fading and contains Rayleigh fading as a special case. Weibull can also model fading scenarios worse than Rayleigh fading for  $c < 2$  [7]. This scenario models multipath fading in both links. Utilizing the expressions for CDF from Table 1 in (5), the outage probability for scenario 2 can be calculated as

$$p_{out}(\gamma_{th}) = 1 - \frac{\Gamma\left(m, \frac{m}{\bar{\gamma}}\gamma_{th}\right)}{\Gamma(m)} \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}} \Gamma\left(1 + \frac{2}{c}\right)^{\frac{c}{2}}\right) \quad (7)$$

**Scenario 3:** In scenario 3, the links between S-R and R-D take Weibull PDF and Rayleigh PDF respectively, which is a special case of both Rayleigh-Generalised Gamma fading and Nakagami-m-Weibull fading scenarios. This scenario is used to model multipath fading in both links in which one link represented by Rayleigh fading is subjected to intense scattering with no line of sight of transmission and the other link represented by Weibull experiences fading that varies from worse to better than Rayleigh fading. Utilizing the expressions for CDF from Table 1 in (5), the outage probability for scenario 3 can be calculated as

$$p_{out}(\gamma_{th}) = 1 - \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}}\right) \exp\left(-\frac{\gamma_{th}}{\bar{\gamma}} \Gamma\left(1 + \frac{2}{c}\right)^{\frac{c}{2}}\right) \quad (8)$$

**Scenario 4:** In scenario 4, the links take Nakagami-m PDF and Nakagami-q PDF. Nakagami-q is a fading distribution which models short term signal variations that span from one-sided Gaussian to Rayleigh fading. Such fading is usually observed on satellite links due to strong ionosphere scintillation. This scenario, therefore, models a system that experiences short term signal variations in both link but one link is always subjected to signal variations worse than Rayleigh fading like the case satellite links suffering from ionosphere scintillation. Utilizing the expressions for CDF from Table 1 in (5), the outage probability for scenario 4 can be calculated as

$$p_{out}(\gamma_{th}) = 1 - \frac{\Gamma\left(m, \frac{m}{\bar{\gamma}}\gamma_{th}\right)}{\Gamma(m)} \left[ Q\left(\alpha(q)\sqrt{\frac{\gamma_{th}}{4\bar{\gamma}}}, \beta(q)\sqrt{\frac{\gamma_{th}}{4\bar{\gamma}}}\right) - Q\left(\beta(q)\sqrt{\frac{\gamma_{th}}{4\bar{\gamma}}}, \alpha(q)\sqrt{\frac{\gamma_{th}}{4\bar{\gamma}}}\right) \right] \quad (9)$$

**Scenario 5:** In scenario 5, the links between S-R and R-D take Rayleigh PDF and  $\eta - \lambda - \mu$  PDF. The  $\eta - \lambda - \mu$  PDF is a generalised small scale fading

distribution which contains  $\lambda-\mu$ ,  $\eta-\mu$ , Gamma, exponential, Hoyt, Nakagami-m, Rayleigh and one-sided Gaussian as special cases [9]. This scenario is used to model multipath fading in both links in which one link represented by Rayleigh fading is subjected to intense scattering with no line of sight of transmission and the other link represented by  $\eta-\lambda-\mu$  experiences a variety of multipath fading that varies from worse to better than Rayleigh fading. Utilizing the expressions for CDF from Table 1 in (5), the outage probability for scenario 5 can be calculated as:

$$p_{out}(\gamma_{th}) = 1 - \exp\left(\frac{-\gamma_{th}}{\bar{\gamma}}\right) \left[ 1 - \left(\frac{2\sqrt{\eta(1+\lambda^2)\hat{b}}}{\hat{r}^2}\right)^{2\mu} \frac{\sqrt{\pi}}{\gamma(u)\hat{c}^{2\mu}\hat{d}^{\mu-0.5}} \sum_{j=0}^{\infty} \frac{1}{j!\Gamma(0.5+\mu+j)} \left(\frac{\hat{d}}{2\hat{c}}\right) \left(\Gamma(2(\mu+j)) - \Gamma\left(2(\mu+j), \frac{\hat{c}\gamma_{th}}{\bar{\gamma}}\right)\right) \right] \quad (10)$$

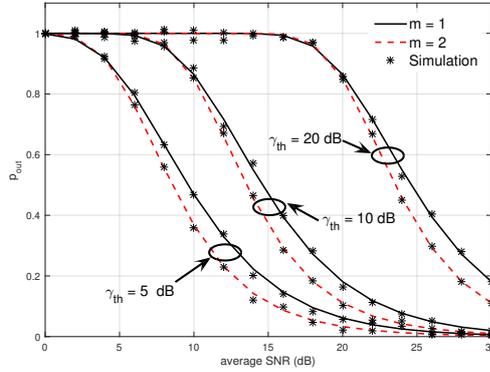
An important point to note here is that the derived expression can be used to calculate the outage performance of the system for any fading scenario. The only condition is the CDF of SNR should be known.

## 5 Results and Discussions

In this section, the analytical results obtained from derived outage probability expression (5) are presented and verified using simulation results. Results are provided for the fading scenarios discussed in Section 4. It is observed in all the plots that the analytical results are in accordance with the results obtained from Monte-Carlo simulations.

### 5.1 Scenario 1: Rayleigh-Generalised Gamma fading

The outage probability against SNR ( $\bar{\gamma}$ ) for scenario 1, Rayleigh-Generalized Gamma fading, for threshold SNR ( $\gamma_{th}$ ) = 5 dB, 10 dB, and 20 dB is shown in Fig. 2. The fading parameters are set at  $v = 1$  and  $m = 1, 2$ . It is observed that  $m = 2$  outperforms  $m = 1$  in all cases, which is expected because of the increase in the fading parameter  $m$  at a constant value of  $v$  and ( $\bar{\gamma}$ ) leads to a reduction in fading severity hence reduced the possibility of an outage. It is noted that increasing the threshold SNR whilst keeping other factors  $m, v, (\bar{\gamma})$  constant increases the outage probability of the system. This is because increasing ( $\gamma_{th}$ ) means more instantaneous SNR ( $\bar{\gamma}$ ) values will fall short of the threshold value hence higher possibility of an outage. It is also observed from Fig. 2 that the curves for outage performances for the same  $m$  and  $v$  but different ( $\gamma_{th}$ ) parameters follow the same trend for a large range of SNR.

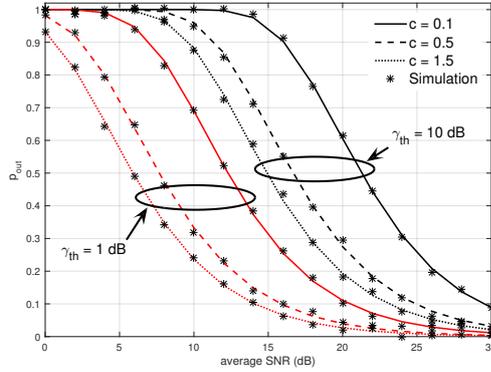


**Fig. 2** Outage probability v/s average SNR for Rayleigh-Generalized Gamma fading.

## 5.2 Scenario 2: Nakagami-m-Weibull fading

The plot of outage probability v/s  $\bar{\gamma}$  for scenario 2, Nakagami-m-Weibull fading, for  $(\gamma_{th}) = 1\text{dB}$  and  $10\text{ dB}$ , is shown in Fig. 3. System performance is evaluated at each threshold value for Weibull parameter  $c = 0.1, 0.5$  and  $1.5$  which represent fading scenarios worse than Rayleigh fading, and Nakagami parameter  $m = 1$  which represents Rayleigh fading. It is observed that the general system behaviour as the value of  $c$  and threshold parameter  $(\gamma_{th})$  varies is similar to that observed in Rayleigh-Generalized Gamma fading, thus the performance improves with increased  $c$  value but gets worse with increased  $(\gamma_{th})$ .

By setting  $m = 1$ , a Rayleigh faded link is evaluated and by setting  $c < 2$  on the other link, worse than Rayleigh fading scenario can be evaluated. It can, therefore, be observed that the performance of the system in this scenario, at  $(\gamma_{th}) = 10\text{dB}$  is noticeably worse than the performance of the Rayleigh-Generalized Gamma fading for  $m = v = 1$ . However, at  $c = 1.5$ , the per-



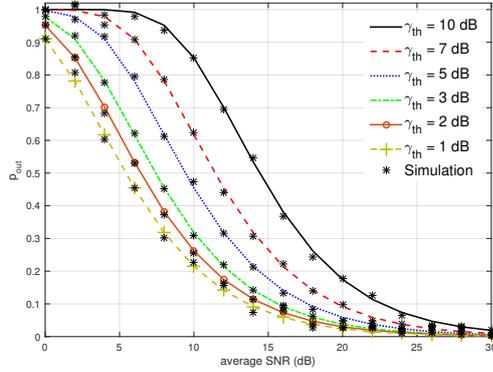
**Fig. 3** Outage probability v/s average SNR for Nakagami-m-Weibull fading.

formance of the system is very close to that of the Rayleigh-Rayleigh fading scenario.

### 5.3 Scenario 3: Rayleigh-Weibull fading

The outage probability against  $\bar{\gamma}$  for scenario 3 (Rayleigh-Weibull fading) for  $(\gamma_{th}) = 1$  dB, 2 dB, 3 dB, 5 dB and 7 dB, is shown in Fig. 4. System performance is evaluated for Weibull parameter  $c = 1$  which represents multipath fading worse than Rayleigh fading.

It is observed that the general system behaviour as the threshold parameter  $(\gamma_{th})$  varies is the similar to that observed in Rayleigh-Generalized Gamma fading and Nakagami-m-Weibull fading, thus the performance worsens as  $(\gamma_{th})$  increases. It can also be observed that the general parallel behaviour at different  $(\gamma_{th})$  values but same  $c$  parameter are also exhibited in this scenario. In this scenario one link being Rayleigh faded link and by setting  $c < 2$ , the other link has been made worse than Rayleigh fading. It observed that the performance of the system in this scenario, at  $(\gamma_{th}) = 5$ dB is similar to that



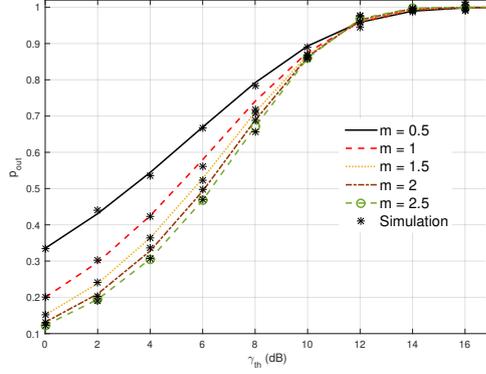
**Fig. 4** Outage probability v/s average SNR for Rayleigh-Weibull fading.

of the Rayleigh-Generalized Gamma fading for  $m = v = 1$  which is effectively Rayleigh-Rayleigh fading scenario. It can, therefore, be observed that at lower values of  $(\gamma_{th})$ , fading in the system can be modelled as a Rayleigh-Rayleigh fading scenario.

#### 5.4 Scenario 4: Nakagami-m - Nakagami-q fading

In this scenario, unlike the previous scenarios, we study the outage performance of the system against the threshold SNR  $(\gamma_{th})$  at various values of fading parameter  $m$  but constant  $q = 0.5$  and  $\bar{\gamma} = 10$  dB, as illustrated in Fig 5. The system is studied at parameter  $m$  set at values 0.5, 1.0, 1.5, 2.0 and 2.5. By setting  $q < 1$ , one link always experiences worse than Rayleigh fading. In the other link, values of  $m < 1$ ,  $m = 1$  and  $m > 1$  indicate worse than Rayleigh, Rayleigh and better than Rayleigh fading respectively.

It is observed that as  $m$  increases, the performance of the system improves just as the case in the Rayleigh-Generalised Gamma and other previous

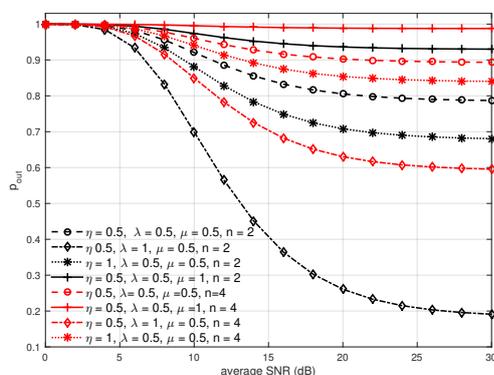


**Fig. 5** Outage probability v/s  $(\gamma_{th})$  for Nakagami-m - Nakagami-q fading at average SNR = 10 dB

scenarios. However, at high values of  $(\gamma_{th}) > 12dB$ , the outage performance equals one for all cases.

### 5.5 Scenario 5: Rayleigh - $\eta - \lambda - \mu$ fading

The outage probability v/s  $\bar{\gamma}$  for scenario 5 i.e. Rayleigh -  $\eta - \lambda - \mu$  fading, for  $(\gamma_{th}) = 10$  dB is shown in Fig. 6. The results are provided for the channel parameters  $\eta = 0.5, 1, \lambda = 0.5, 1$ , and  $\mu = 0.5, 1$ . In this analysis,  $\delta_x^2$ , which is the average power of the in-phase component is set at 1. It is observed that, out of these cases, the best outage performance is obtained at  $\eta = \mu = 0.5$  and  $\lambda = 1$ . This shows that the more the propagation environment becomes non-homogeneous the better the performance. It is observed that increasing  $\eta$  from 0.5 to 1 whilst keeping other parameters constant improves the performance of the system because as  $\eta$  approaches 1, the  $\eta - \lambda - \mu$  fading approaches Rayleigh fading.



**Fig. 6** Outage probability v/s average SNR for Rayleigh -  $\eta - \lambda - \mu$  fading

## 6 Conclusion

A universal expression for outage probability has been derived for dual-hop DF relay system. The analysis is done considering generalized fading scenarios i.e. no restrictions were bound on the PDF of SNR of the transmission link. This paper demonstrates a convenient way to analyse the outage behaviour of the relay-aided system by utilizing the CDF of the per-hop SNR. Simulation results have been used to verify the validity of derived analytical expressions. Illustrations are provided by choosing the PDF of channels between S-R and R-D links to parameterise the commonly encountered practical fading scenario faced by current and future wireless communication systems.

Funding: Not applicable

Conflicts of interest/Competing interests: The author declare that there is no conflict of interest.

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