國 立 交 通 大 學

電 信 工 程 學 系

碩 士 論 文

合 作 式 自 動 重 傳 請 求 使 用 投 機 式 束 波 成 形

Cooperative ARQ via Opportunistic Beamforming

研 究 生：李晉豪

指導教授：伍紹勳　博士

中 華 民 國 九十七 年 八 月

合作式自動重傳請求使用投機式束波成形

Cooperative ARQ via Opportunistic Beamforming

研 究 生：李晉豪　　Student：Jing-Haw Li

指導教授:伍紹勳　　Advisor:Dr. Sau-Hsuan Wu

國 立 交 通 大 學

電 信 工 程 學 系 碩 士 班

碩 士 論 文

A Thesis
Submitted to Department of Communication Engineering
College of Electrical and Computer Engineering
National Chiao Tung University
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science
in
Communication Engineering
August 2008
Hsinchu, Taiwan, Republic of China

中華民國九十七年八月

合 作 式 自 動 重 傳 請 求 使 用 投 機 式 束 波 成 形研究

生:李晉豪　　　　　　　　　指導教授:伍紹勳

國立交通大學電信工程學係 碩士班

摘要

針對於合作式通訊上在解碼傳送與放大傳送的兩個協定上使用合作式自動重傳投機式束波成形來探討錯誤率與有效的傳送資料量，藉由錯誤率的分析可知，在解碼傳送的協定上，使用兩個最佳的接力端幫助傳輸可到達 的錯誤率與使用所有解碼成功的接力端來幫助傳輸是幾乎一樣的。然而，針對於放大傳送的協定而言，假設全部可用的接力端爲M個，使用一個最佳的接力端與全部使用所有的接力端的錯誤率有M!倍的差距。因此，我們探討使用i個最佳的接力端來傳輸的效能與使用所有接力端的效能，此外， 我們利用錯誤率分析的結果，來分析合作式重傳機制在時間上與空間上的 自由度，最後可知，對於解碼傳送協定，使用type-IV的機制可以得到最好 的傳送資料量，而針對放大傳送協定，是要使用更多的接力端才可以增加傳送資料量。

Cooperative ARQ via Opportunistic Beamforming

Student:Jing-Haw Li Advisor:Dr.Sau-Hsuan Wu

Department of Communication Engineering
National Chiao Tung University

Abstract

The outage probability and effective throughput of cooperative automatic request for retransmission (ARQ) are investigated for opportunistic cooperative beamforming using i relays (OC-BF-i) for decode-and-forward (DF) and amplify-and-forward (AF) protocols. According to the outage analysis, the outage performance of the proposed opportunistic cooperation schemes of using the two relay nodes is almost indistinguishable from that of using all decoding relays. However, the cooperative scheme with total relays number M for AF protocol has M! SNR offset gap between opportunistic relaying and using all relays transmission. Thus, we also discuss the outage performance for AF OC-BF-i. Motivated by outage result, cooperative ARQ schemes are developed for opportunistic cooperative beamforming for these two protocols to exploit the spatial and temporal cooperative diversities simultaneously. Analysis shows that the effective way to improve throughput is using type-IV ARQ scheme for DF OC-BF scheme. For AF OC-BF, the throughput can be more effectively improved by using more best relays.

誌謝

能夠完成兩年的碩士學業，首先要感謝的是我的指導教授伍紹勳老師，不僅耐心給予我很大的空間，讓我自由的去找尋想深入探索的研究方向與自由的發揮，在我遇到困難的時候，老師也適時的從旁協助。除了專業領域的指導，老師也常常將研究必須抱持的態度延伸到生活態度上，讓我獲益匪淺。 此外，感謝趙必昌學長在作計畫的時候給予我許多的幫助，邱麟凱學長在我做研究時不厭其煩的與我討論研究上的困難之處。小p、Jason一起與我度過許多修課的日子，一起經歷作project的日子，一起成長，一起努力，謝謝他們這兩年來的幫助與陪伴。感謝penny學妹常常提供實驗室零食與笑話，實驗室有你，整個氣氛都不一樣，。同屆的同學們一起走過這段寫論文的生活，以及實驗室的其他學長，學弟妹一起互相在研究上及電腦資訊上的交流，讓這兩年的碩士生活除了研究外，更多了許多值得回憶的事情。並且感謝和我一起從成大唸到交大的大學同學兼室友，一起打球和外出旅遊，謝謝室友陪我許多日子。 最後將本論文獻給我的家人，感謝他們的支持，讓我無後顧之憂的專心在學術研究上，而能完成本論文並取得碩士學位。

Contents

List of Figures

Chapter 1

Introduction

In wireless communications, the signal qualities often suffer from severe channel fades. The fading effects of wireless channels can be effectively compensated through the diversity. The signal is transmitted over the independent channel realization with suitable receiver combining to average the channel fading. The spatial diversity can be exploited by using multiple-input and multiple-output (MIMO) antennas [1]. However, due to the space limitation of mobile devices, it is sometimes impractical to use multiple antennas to obtain spatial diversities. In [2, 3], the spatial diversity of virtual antenna arrays is introduced by using cooperative relaying. This work obtains the repetition based cooperative diversity algorithm and space-time-code (STC) diversity algorithm to achieve full diversity for decode-and-forward (DF) protocol. It is further shown in [4, 5] that the full diversity of cooperative transmission can be achieved even using the node that with the best channel link quality between relays and destination for relaying often referred to as the opportunistic relaying.

Extended from the concept of opportunistic relaying, cooperative beamforming (Co-BF) schemes are also introduced in [6, 7]. Motivated by the simplicity and effectiveness of opportunistic relaying, some more recent efforts have been made to improve the performance of opportunistic relaying by choosing more best relays. Approximated analysis for the outage probabilities of some opportunistic cooperative beamforming (OC-BF) schemes can be found in [8] and it provides that the performance using best two relays can achieve the performance with all potential relays for beamforming. However, the work in [7] provides that the performance gap between opportunistic relaying and cooperative beamforming (Co-BF) with M relays is $M!$ times for amplify-and-forward (AF) protocol.

In view of the advantage of opportunistic relaying, we investigate the outage performance of (DF) and (AF) beamforming by choosing the best few nodes for relaying. For brevity, this beamforming scheme is referred to as the opportunistic cooperative beamforming (OC-BF) in the sequel. Our results show that, in contrast to the DF OC-BF scheme, the performance of the AF OC-BF scheme doesn't quickly converge to that of the AF Co-BF as the number of best nodes increases. The gap between the outage probabilities of the OC-BF and the Co-BF is characterized by using the diversity analysis in high signal to noise ratio (SNR) regime. In addition, the AF OC-BF performs better than the DF OC-BF when the number of beamforming nodes is greater than one and the performance of the AF opportunistic relaying is very closed to that of the DF opportunistic relaying. Thus, for DF OC-BF, choosing the best two relays is sufficient to achieve the performance of DF Co-BF. While for AF protocols, it requires more best relays to achieve the outage performance of AF Co-BF.

In contrast to the rich research results in the outage analysis for cooperative transmission, the performance of cooperative automatic request for retransmission (ARQ) is rather less investigated. The average throughput of a cooperative hybrid-ARQ (HARQ) scheme is reported in [9] using the distributed space-time-code (DSTC) scheme. Motivated by the effectiveness of opportunistic cooperation and the extra degrees of freedom brought upon by ARQ. In this research, we attempt to simultaneously exploit the spatial and temporal diversities via cooperative ARQ. We proposes several ARQ transmission schemes to analyze the corresponding outage and the effective throughput of cooperative

ARQ for the DF and AF opportunistic cooperative beamforming schemes.

Our results show that the outage performance can be improved a lot by adding more one best relay for AF OC-BF and the outage performance by using best two relays can achieve the performance of Co-BF for DF protocol. Based on these results, we further investigate the outage performance and characterize the average throughput for cooperative ARQs of OC-BF, respectively. Analysis shows that the effective throughput can be increased by using ARQs scheme for DF and AF scheme in low SNR regime. Beside, the throughput can be improved a lot by adding more one best relay than using more one time ARQ scheme for AF protocol.

Chapter 2

System Model

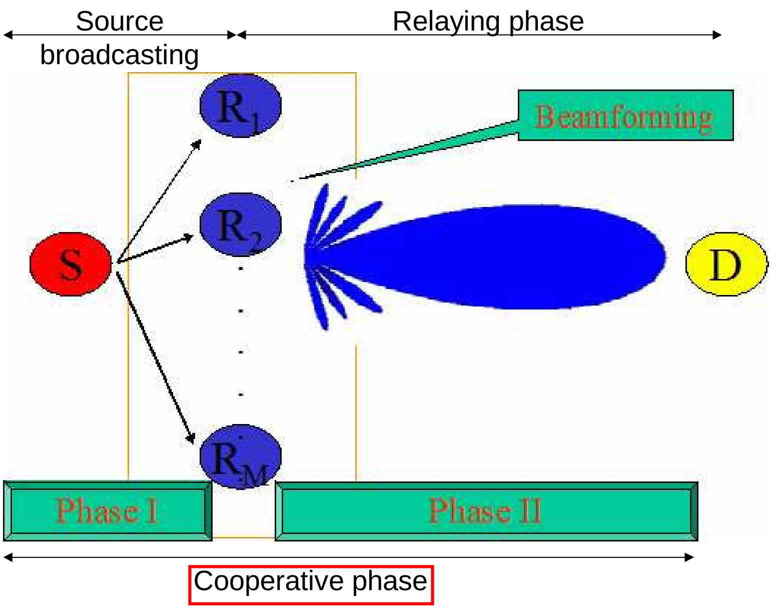

Figure 2.1: Cooperative system.

We consider a cooperative relay network with two phase transmission. There are M potential relays in the network to help re-transmit signals by using AF and DF protocols as shown in Fig. 2.1. In phase I, the source transmit signal to all relay nodes and destination. For DF protocol, the decoded correctly relay nodes collaboratively retransmit signal to destination. However, the relay node in AF protocol amplify the received signal to destination. Following, we individual describes the system model as follow:

2.1 System Model for DF Protocol

The cooperative relay network with two phase transmission for DF protocol. The source broadcasts the signal to all potential relays and destination in the phase one transmission. The received signals at the relay node i and destination are

$$r_i = \sqrt{P_s} h_{s,i} x + n_{s,i}, i = 1, 2 \cdots M. \tag{2.1}$$

$$r_{d,1} = \sqrt{P_s} h_{s,d} x + n_{s,d} \tag{2.2}$$

where the $\sqrt{P_s}$ is the transmitted power at the source node. The $h_{s,i}$ and $h_{s,d}$ are the source to relay and source to destination complex Gaussian channel with zeros mean and variance equal to one. The $n_{s,i}$ and $n_{s,d}$ are the additive white Gaussian noise (AWGN) with zero mean and variance N_0. In the phase II that we called the relaying phase, the successfully decoded relays transmit signal to destination collaboratively. For brevity in the sequel, we called the set that obtains the successfully decoded relays as decoding set,i.e.,$\mathcal{D}(\mathcal{S})$. The received signal to destination in relaying phase is

$$r_{d,2} = \sum_{i \epsilon \mathcal{D}(\mathcal{S})} \sqrt{P_r} h_{i,d} w_{i,DF} x + n_d \tag{2.3}$$

where $\sqrt{P_r}$ is the total relay power and $h_{i,d}$ is between relay and destination complex Gaussian channel with zero mean and variance one, and the n_d is the AWGN noise at the destination. The $w_{i,DF}$ is the beamforming weight to combat the channel fading and $\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |w_{i,DF}|^2 = 1$. We assume that the all relay nodes know the channel state information (CSI) between the relay nodes and destination with perfect feedback from destination. The total received signal to noise ratio (SNR) can be shown as:

$$SNR_d = \frac{P_s|h_{s,d}|^2}{N_0} + \frac{P_r|\sum_{i\epsilon\mathcal{D}(\mathcal{S})} h_{i,d}w_{i,DF}|^2}{N_0} \tag{2.4}$$

The optimum weight can be obtained by maximizing received SNR after two phase combing. By cauchy inequality with equality hold, the $w_{i,DF} = kh_{i,d}\dagger$ under constrain $\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |w_{i,DF}|^2 = 1$ is shown as

$$k^2 \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2 = 1$$

$$k = \frac{1}{\sqrt{\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2}} \tag{2.5}$$

The optimum weight is given by:

$$w_{i,DF} = \frac{h_{i,d}^{\dagger}}{\sqrt{\sum_{i\epsilon\mathcal{D}(\mathcal{S})} |h_{i,d}|^2}} \tag{2.6}$$

Substituting the optimum weight into equation (2.4), we can obtain the maximum received SNR as

$$SNR_{max,DF} = \frac{P_s|h_{s,d}|^2}{N_0} + \frac{\sum_{i\epsilon\mathcal{D}(\mathcal{S})} P_r|h_{r_i,d}|^2}{N_0} \tag{2.7}$$

$$= (1-\alpha)\gamma\alpha_0 + \alpha\{\sum_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\beta_i\} \tag{2.8}$$

where $\gamma = \frac{P}{N_0}$, $P_s = (1-\alpha)P$, $P_r = \alpha P$ and $\beta_i = |h_{i,d}|^2$ and $\alpha_0 = |h_{s,d}|^2$ are $\sim Exp(1)$ The α is the factor to adjust power between source and relay nodes ie. $0 < \alpha < 1$. $w = (1-\alpha)\gamma\alpha_0$ is exponential distribution with parameter $\lambda_0 = \frac{1}{(1-\alpha)\gamma}$ and $\alpha\gamma\beta_i$ is also exponential random variable with parameter $\frac{1}{\gamma\alpha}$

2.2 System Model for AF Protocol

In the beginning of the transmission, the source node broadcasts signal to all relays and the destination. The received signals at the relay node i and the destination are

$$r_i = \sqrt{P_s} h_{s,i} x + n_{s,i}, i = 1, 2 \cdots M. \tag{2.9}$$

$$r_{d,1} = \sqrt{P_s} h_{s,d} x + n_{s,d} \tag{2.10}$$

where the $\sqrt{P_s}$ is the transmitted power at the source node. The $h_{s,i}$ and $h_{s,d}$ are complex Gaussian channel of the source to relay and source to destination channel. The $n_{s,i}$ and $n_{s,d}$ are the additive white Gaussian noise (AWGN) with zero mean and variance N_0. The relays received signal from the phase I and amplify the signal to destination in the relaying phase. The signal to be transmitted from the relay is

$$x_i = \frac{r_i}{\sqrt{E\{|r_i|^2\}}} = \frac{\sqrt{P_s} h_{s,i} x + n_{s,i}}{\sqrt{P_s |h_{s,i}|^2 + N_o}} \tag{2.11}$$

All relay nodes collaboratively transmit signal to the destination, with the $i-th$ relay weighted by $w_{i,AF}$. Thus, the received signal at the destination is

$$\begin{aligned} r_{d,2} &= \sum_{i=1}^{M} \sqrt{P_r} w_{i,AF} h_{i,d} x_i + n_d \\ &= \sum_{i=1}^{M} \frac{\sqrt{P_s P_r} w_{i,AF} h_{s,i} h_{i,d} x}{\sqrt{P_s |h_{s,i}|^2 + N_0}} + \sum_{i=1}^{M} \frac{\sqrt{P_r} w_{i,AF} h_{i,d} n_{s,i}}{\sqrt{P_s |h_{s,i}|^2 + N_0}} + n_d \\ &= \sum_{i=1}^{M} w_{i,AF} \tilde{h}_i x + \tilde{n}_d \end{aligned} \tag{2.12}$$

where the P_r is the total relay power, $h_{i,d}$ is the complex Gaussian channel between relay and destination , and the n_d is the AWGN noise at the destination. To keep the total relay power is P_r, thus the beamforming weight satisfy $\sum_{i=1}^{M} |w_{i,AF}|^2 = 1$. In equation(2.12), we define an equivalent channel and noise term to simply the expression.

The equivalent channel through relay i is

$$\tilde{h}_i = \frac{\sqrt{P_s P_r} h_{s,i} h_{i,d}}{\sqrt{P_s |h_{s,i}|^2 + N_0}} \tag{2.13}$$

and equivalent noise $\tilde{n_d}$ is circularly symmetric Gaussian distributed as

$$\tilde{n}_d \sim CN(0, (1 + \sum_{i=1}^{M} |w_{i,AF}|^2 |\mathbf{H}_{i,i}|^2) N_0) \tag{2.14}$$

where $\mathbf{H}$ is the diagonal matrix whose $i - th$ element $(\mathbf{H}_{i,i})$, $\mathbf{H}_{i,i} = \frac{\sqrt{P_r} h_{i,d}}{\sqrt{P_s |h_{s,i}|^2 + N_0}}$.

Maximum ratio combing (MRC) of the signal over two transmission phases. Thus, the total received signal to noise ratio (SNR) can be shown as

$$SNR_d = \frac{P_s |h_{s,d}|^2}{N_0} + \frac{|\sum_{i=1}^{M} w_i \tilde{h}_i|^2}{N_0 (1 + \sum_{i=1}^{M} |w_i \mathbf{H}_{i,i}|^2)} \tag{2.15}$$

we can rewrite the second term in equation(2.15) as

$$\frac{\mathbf{w}^\dagger \mathbf{h} \mathbf{h}^\dagger \mathbf{w}}{N_0 \mathbf{w}^\dagger (\mathbf{I} + \mathbf{H}\mathbf{H}^\dagger) \mathbf{w}}. \tag{2.16}$$

where $\mathbf{w} \triangleq [w_1 w_2 \cdots w_M]^T$, $\mathbf{h} \triangleq [h_1 h_2 \cdots h_M]^T$

From [7], the optimum beamforming weight is given by

$$\mathbf{w}^\dagger = \frac{(\mathbf{I} + \mathbf{H}\mathbf{H}^\dagger)^{-1} \mathbf{h}}{||(\mathbf{I} + \mathbf{H}\mathbf{H}^\dagger)^{-1} \mathbf{h}||_2} \tag{2.17}$$

Substituting the optimum beamforming weight into the total received SNR formula, thus it can find the maximum received SNR as follow:

$$\begin{aligned} SNR_{opt} &= \frac{P_s |h_{s,d}|^2}{N_o} + \sum_{i=1}^{M} \frac{P_s P_r |h_{s,i}|^2 |h_{i,d}|^2}{P_s |h_{s,i}|^2 + P_r |h_{i,d}|^2 + N_0} \\ &= (1 - \alpha)(\gamma \alpha_0) + \sum_{i=1}^{M} \frac{\alpha (1 - \alpha) \gamma^2 \alpha_i \beta_i}{1 + (1 - \alpha) \gamma \alpha_i + \alpha \gamma \beta_i} \end{aligned} \tag{2.18}$$

where the $\gamma = \frac{P}{N_0}$, and $\alpha_i = |h_{s,i}|^2$, $\beta_i = |h_{i,d}|^2$ are $\sim Exp(1)$. Especially, the $w = (1-\alpha)(\gamma\alpha_0)$ is exponential distribution with parameter $\lambda_0 = \frac{1}{(1-\alpha)\gamma}$. $(1-\alpha)\gamma\alpha_i$ and $\alpha\gamma\beta_i$ are also exponential distribution with parameter with parameter $\lambda_1 = \frac{1}{(1-\alpha)\gamma}$, $\lambda_2 = \frac{1}{\alpha\gamma}$

Chapter 3

Outage Analysis for Opportunistic Cooperative Beamforming

The outage analysis is widely studied of the cooperative scheme for decode-and-forward (DF) and amplify-and-forward (AF) protocols. The outage probability of the cooperative beamforming using (AF) scheme wa studied in [7] and compared with opportunistic relaying that choose the best relay between the relay and destination link. It investigates the performance gap between cooperative beamforming and opportunistic relaying and shows the SNR gap is $M!$ times. In addition, the outage probability of cooperative beamforming using the decode-and-forward (DF) scheme was also investigated in [8]. In particular, the approximation formula of the outage probability was provided in [10], where it using the best k out of M relays collaboratively transmit signal to destination. It provides that the outage performance of opportunistic cooperative beamforming using best two relays (OC-BF-2) which chooses from relay to destination link is almost indistinguishable from cooperative beamforming. Motivated by this research result, we major investigate outage probability that using best k out of M relays to transmit signal to the destination for (AF) protocol in this section. Our result shows that the performance gap can be reduced by using more best relays and the gap can reduced over half by adding more one relay node for AF protocol.

3.1 AF Protocol

Assume that there are total M relays in the network. In phase I, the source node broadcasts the signal to the relays and the destination. By choosing the best relay which channel quality is the best between relay to destination link. In the end of phase II, the receiver uses the channel information to combine the two phases signal by (MRC). The entire exact SNR is shown as

$$SNR_{O-R} = (1-\alpha)(\gamma\alpha_0) + \max_{i\epsilon(1,2\cdots M)} \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} \quad (3.1)$$

To simplify the analysis in the high SNR regime, the second term in equation (3.1) can be expressed the harmonic mean random variable as

$$\frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} \sim \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i}$$

The outage probability is

$$\begin{aligned} P_{out} &= P\{SNR < 2^{(2R)}-1\} = P\{SNR < \delta\} \\ &\approx P\{\gamma\alpha_0 + \max_{i\epsilon(1,2\cdots M)} \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} < \delta\} \\ &= \int_0^\delta P\{\max_{i\epsilon(1,2\cdots M)} Z_i < \delta - w\} f_W(w)dw \\ &= \int_0^\delta \{P\{Z_i < \delta - w\}\}^M f_W(w)dw \end{aligned} \quad (3.2)$$

where $\delta \triangleq 2^{(2R)}-1$,$Z_i \triangleq \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i}$ and $w \triangleq (1-\alpha)\gamma\alpha_i \sim Exp(\lambda_0)$ with pdf $f_W(w) = \lambda_0 e^{(-\lambda_0 w)}$, $(1-\alpha)\gamma\alpha_i \sim Exp(\lambda_1)$,$\alpha\gamma\beta_i \sim Exp(\lambda_2)$

From equation(3.2), we need obtain the probability density function(PDF) or cumulative distribution(CDF) of the harmonic random variables to calculate outage probability. The probability density function(PDF) or cumulative distribution(CDF) of the harmonic random variables is obtained by [11] and it are summarized bellow in theorem 1 and theorem 2.

Theorem 1. {*The CDF of Harmonic Mean of Two Exponential Random Variables [11]*}

Let the X_1 and X_2 be two independent random variables with the parameter λ_1 and λ_2 respectively, i.e. $X_i \sim Exp(\lambda_i), i = 1, 2$. Then the cumulative distribution function(CDF) of $X = \frac{X_1 X_2}{X_1 + X_2}$ is given by

$$F(x) = 1 - 2x\sqrt{\lambda_1\lambda_2}exp(-x(\lambda_1 + \lambda_2))K_1(2x\sqrt{(\lambda_1\lambda_2)}) \tag{3.3}$$

Theorem 2. {*The PDF of Harmonic Mean of Two Exponential Random Variables [11]* } *Let the X_1 and X_2 be two independent random variables with the parameter λ_1 and λ_2 respectively, i.e. $X_i \sim Exp(\lambda_i), i = 1, 2$. Then the probability density function(PDF) of $X = \frac{X_1 X_2}{X_1 + X_2}$ is given by*

$$f(x) = \lambda_1\lambda_2 x \exp(-x(\lambda_1 + \lambda_2))\{\frac{\lambda_1 + \lambda_2}{\sqrt{\lambda_1\lambda 2}}K_1(2x\sqrt{\lambda_1\lambda_2}) + 2K_0(2x\sqrt{\lambda_1\lambda_2})\} \tag{3.4}$$

where the $K_0(\cdot)$ and $K_1(\cdot)$ are the zeroth-order modified Bessel function of the second kind and the first-order modified Bessel function of the second kind.

From [12], the function of $K_1(\cdot)$ can be approximated as $K_1(x) \approx \frac{1}{x}$ for the small x. Thus, we can approximate the CDF of the harmonic random variable as $F(x) \approx 1 - exp\{-x(\lambda_1 + \lambda_2)\}$ when x is small. Obviously, the harmonic mean random variable can be approximated as exponential random variable with parameter $(\lambda_1 + \lambda_2)$.

Substituting theorem 1 into the (3.2), the outage probability can be expressed as

$$\begin{aligned} P_{out,O-R} &= \int_0^{\delta} \{P\{Z_i < \delta - w\}\}^M f_W(w)dw \\ &= \int_0^{\delta} \{1 - 2(\delta - w)\sqrt{(\lambda_1\lambda_2)} e^{(-(\delta-w)(2(\lambda_1+\lambda_2)))} K_1(2(\delta - w)\sqrt{(\lambda_1\lambda_2)})\}^M f_W(w)dw \end{aligned}$$

Because $2(\delta - w)\sqrt{(\lambda_1\lambda_2)} = \frac{2(\delta-w)\alpha(1-\alpha)}{\gamma}$ is small in the high SNR regime when R is fixed, $K_1(x)$ can be approximated as $\frac{1}{x}$ when x is small. As a result, the harmonic mean random variables can be approximated as exponential random variables with parameter $(\lambda_1 + \lambda_2)$. Thus, the outage can be expressed as

$$P_{out,O-R} \approx \int_0^{\delta} \{1 - e^{(-(\delta-w)(2(\lambda_1+\lambda_2)))}\}^M f_W(w)dw$$

According to Binomial theorem,

$$(x + y)^n = \sum_{k=0}^{n} C_k^n x^k y^{n-k} \tag{3.5}$$

we can obtain the outage probability for opportunistic relaying is given by

$$P_{out,O-R} = \sum_{i=0}^{M} C_i^M (-1)^i \lambda_0 \frac{e^{(-(\lambda_1+\lambda_2)\delta i)}}{(\lambda_0 - (\lambda_1 + \lambda_2)i)} \{e^{-\lambda_0-(\lambda_1+\lambda_2)\delta}\}. \tag{3.6}$$

where Z_i is exponentially distributed with parameter $\lambda_1 + \lambda_2$. For simplify the following derivation, we define an order statistic set $\{Z_1, Z_2, \cdots, Z_M\}$ with order $Z_M^{'} > Z_{M-1}^{'} > \cdots > Z_1^{'}$

3.1.1 Cooperative Beamforming (Co-BF)

Different from the opportunistic relaying that chooses the best relay from the relay to destination channel link, the cooperative beamforming uses all potential relays to help transmission in the phase II. The outage formula at the high SNR regime can be approximated as follow:

$$\begin{aligned} P_{out,Co-BF} &\approx P\{(1-\alpha)\gamma\alpha_0 + \sum_{i=1}^{M} Z_i < \delta\} \\ &= \int_0^{\delta} P\{V < \delta - w\} f_W(w) dw \\ &= \frac{(2\lambda)^M}{(M-1)!} \int_0^{\delta} \int_0^{\delta-w} v^{M-1} e^{-(\lambda_1+\lambda_2)v} dv f_W(w) dw \end{aligned} \quad (3.7)$$

where V is sum of M exponential random variables, and $V = \sum_{i=1}^{M} Z_i$ is the gamma distribution $\sim \Gamma(M, 1/(\lambda_1 + \lambda_2))$ with pdf $f_v(v) = \frac{(\lambda_1+\lambda_2)^M v^{(M-1)} e^{-(\lambda_1+\lambda_2)v}}{(M-1)!}$. From [13], the integral formula is shown bellow:

$$\int_0^{u} x^n e^{-ax} dx = \frac{n!}{a^{n+1}} - e^{-ua} \sum_{k=0}^{n} \frac{n!}{k!} \frac{u^k}{a^{n-k+!}} \quad (3.8)$$

$$\int_0^{a} x^{b-1} (a-x)^{c-1} e^{\beta x} dx = B(c,b) a^{c+b-1} {}_1F_1(b; c+b; \beta a) \quad (3.9)$$

where $B(\alpha, \beta) = \frac{(\alpha-1)!(\beta-1)!}{(\alpha+\beta-1)!}$ is the Beta function and ${}_1F_1(\alpha; \beta; z) = \frac{z^{(1-\beta)} \int_0^z e^t t^{\alpha-1} (z-t)^{\beta-\alpha-1} dt}{B(\alpha, \beta-\alpha)}$ is the Confluent hypergeometric function.

Thus, we can obtain the outage probability of cooperative beamforming for AF protocol in high SNR approximation is give by

$$P_{out,Co-BF} = \{(1 - e^{(-\lambda_0 \delta)})\} - \lambda_0 e^{(-(\lambda_1+\lambda_2)\delta)} \sum_{k=0}^{M-1} \frac{(\lambda_1+\lambda_2)^k}{k!} Y_k \quad (3.10)$$

where $Y_k = \int_0^{\delta} e^{(\lambda w)} (\delta - w)^k dw$ and we can use equation (3.9) to express as

$$\begin{aligned} Y_k &= \int_0^{\delta} e^{(\lambda_0 - (\lambda_1+\lambda_2) w)} (\delta - w)^k dw \\ &= B(k+1, 1) \delta^{(k+1)} {}_1F_1(1; k+2; (\lambda_0 - (\lambda_1 + \lambda_2))\delta). \end{aligned} \quad (3.11)$$

Similar results for the above two cases at high SNR regime are also provided in [7] and it also emphasizes the performance gap between these two case are $M!$ times.

3.1.2 Opportunistic Cooperative Beamforming Using Two Relays (OC-BF-2)

Motivated by the research result that provided in [10], it shows that the outage probability uses best two relays which chooses from the relay to destination link can obtain the similar performance as cooperative beamforming in (DF) protocol. Here, we investigate the outage performance that chooses best two relays (OC-BF-2) for (AF) protocol and compare it with opportunistic relaying and cooperative beamforming case.

$$\begin{aligned} P_{out,Oc-BF-2} = &= P\{(1-\alpha)\gamma\alpha_0 + \max_{i,j}(Z_i + Z_j) < \delta\} \\ &= \int_0^\delta P\{(Z_M^{'} + Z_{M-1}^{'}) < \delta - w\} f_W(w) dw \end{aligned} \tag{3.12}$$

From (3.12), we need to obtain the joint probability density function of $Z_M^{'}$ and $Z_{M-1}^{'}$ in the order statistics set $\{Z_1^{'}, Z_2^{'} .... Z_M^{'}\}$ where $Z_{(i)} < Z_{(j)}, i < j$. From [14], it provides that the joint probability density function for any order of i, and j.

Theorem 3. *Let $X_{(1)}, X_{(2)} ..... X_{(n)}$ be the order statics of independent and identically distributed continuous random variables X_1, X_2,....X_n, with the common probability density function and probability distribution function f, F, respectively. Then for $x < y$, $f_{i,j}(x, y)$, the joint probability density function of $X_{(i)}$ and $X_{(j)}$ $(i < j)$, is given by*

$$\begin{aligned} f_{i,j}(x,y) &= \frac{n!}{(i-1)!(j-i-1)!(n-j)!} f(x) f(y) \\ &\times [F(x)]^{i-1}[F(y)-F(x)]^{j-i-1}[1-F(y)]^{n-j} \end{aligned} \tag{3.13}$$

Substituting the theorem 3 into (3.12), the outage probability of OC-BF-2 is shown as follow

$$P_{out,Oc-BF-2} \approx \int_0^{\delta}\int_0^{\frac{\delta-w}{2}}\int_{Z'_{M-1}}^{\delta-w-Z'_{M-1}} f_{Z'_{M-1},Z'_M}(Z'_{M-1},Z'_M)dZ'_{M-1}dZ'_M dw$$
$$= \frac{M!}{(M-2)!}(\lambda_1+\lambda_2)\lambda_0 e^{-\lambda_0\delta}\{C-D\}. \quad (3.14)$$

where C and D are given by

$$C = \sum_{p=0}^{M-2} C_p^{M-2}\frac{(-1)^p}{(\lambda_1+\lambda_2)(2+p)}\{\frac{e^{(\lambda_0\delta)}-1}{\lambda_0} - \frac{1-e^{(-\lambda_1+\lambda_2(1+p/2)-\lambda_0\delta)}}{\lambda_1+\lambda_2(1+p/2)-\lambda_0}\}$$

$$D = \begin{pmatrix} \frac{1}{(\lambda_1+\lambda_2-\lambda_0)^2} - e^{(-(\lambda_1+\lambda_2-\lambda_0)\delta)}\{\frac{\delta}{(\lambda_1+\lambda_2-\lambda_0)} + \frac{1}{(\lambda_1+\lambda_2-\lambda_0)^2}\} & ,q=0 \\ \sum_q^{M-2} C_q^{M-2}\frac{(-1)^q}{(\lambda_1+\lambda_2)q}\{\frac{1-e^{(-(\lambda_1+\lambda_2-\lambda_0)\delta)}}{(\lambda_1+\lambda_2-\lambda_0)} - \frac{1-e^{-(\delta t))}}{t}\} & ,q\neq 0 \end{pmatrix}$$
$$t = \{\tfrac{3}{2}(\lambda_1+\lambda_2)-\lambda_0\}q$$

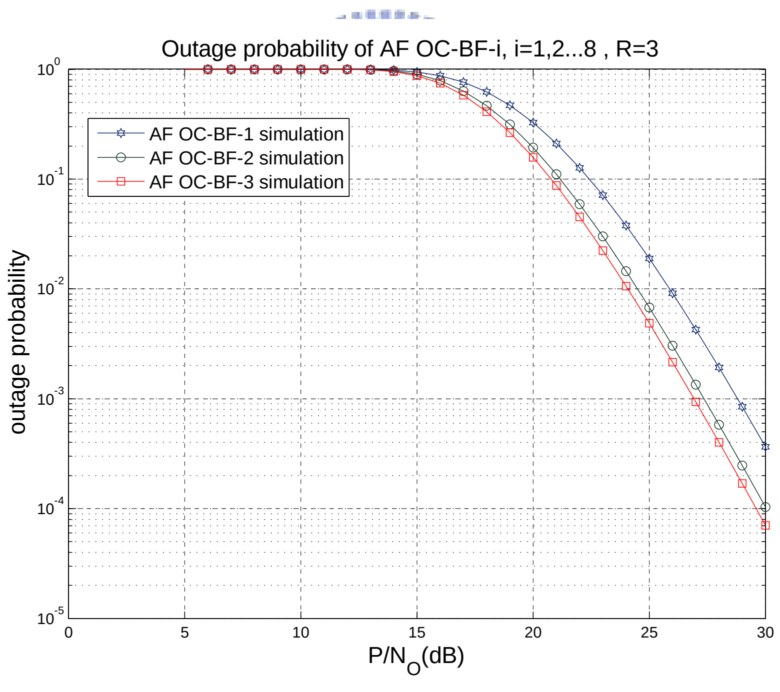

Figure 3.1: The comparison the outage performance between O-R,OC-BF-2 and Co-BF for AF protocol (M=3, R=3, $\alpha = 0.5$).

The outage probability with 2.5 dB gap between AF Co-BF and AF OC-BF-2 with $M = 8$ at $R = 3$. From Fig.3.1 and Fig.3.2, we can observe that the SNR gap between

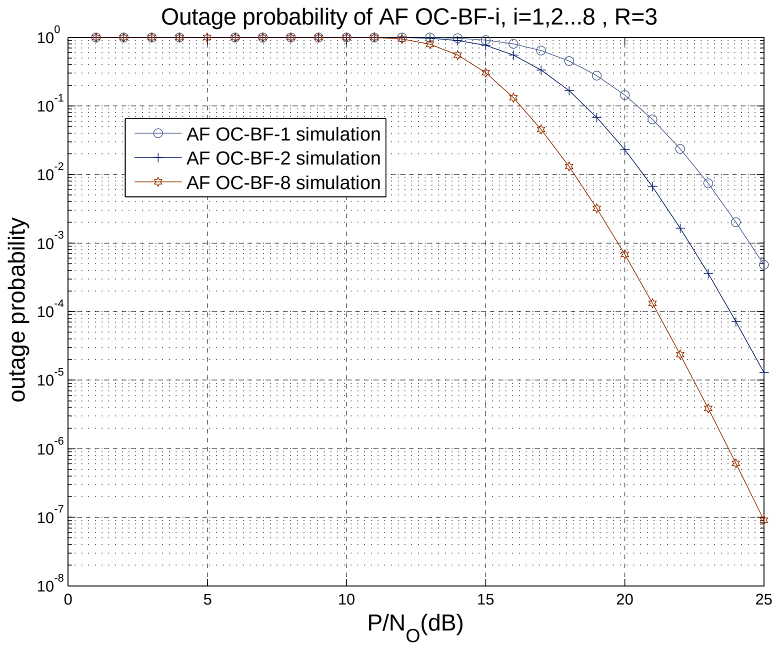

Figure 3.2: The comparison the outage performance between O-R, OC-BF-2 and Co-BF for AF protocol, (M=8, R=3,$\alpha = 0.5$).

CO-BF and OC-FB-2 will be larger when the total relay number becomes large.

3.1.3 Opportunistic Cooperative Beamforming Using i Relays (OC-BF-i)

From Fig. 3.1, it is obviously that uses more best relays can improve the outage performance. Although, the OC-BF-2 can improve the performance a lot in small M. However, When the M becomes large, the SNR gap between the OC-BF-2 and Co-BF becomes larger. According to the above observation, we investigates the outage performance for opportunistic cooperative beamforming using i relays to reduce the performance gap.

$$\begin{aligned} P_{out,Oc-BF-i} &= P\{(1-\alpha)\gamma\alpha_0 + \sum_{i=M-i-1}^{M} Z_i^{'} < \delta\} \\ &= \int_0^{\delta} P\{\sum_{i=M-i-1}^{M} Z_i^{'} < (\delta - w)\} f_W(w) dw \end{aligned} \quad (3.15)$$

From equation (3.15), we should obtain the CDF of sum of top i largest exponential random variables.

From [15], the CDF of sum of the top order statistics for independent exponential random variables is given in theorem 4.

Theorem 4. *Let the* $\{X_{(1)} < X_{(2)} \cdots < X_{(n)}\}$ *be the order statistics from n independent distributed exponential random variables with parameter* μ *and the partial top sum is defined as* $T_i = \sum_{j=i+1}^{n} X_{(j)}, 0 \leq i \leq n-1$. *The complementary cumulative density function (CCDF) of the* T_i *is given as follow:*

$$P\{T_i > t\} = \sum_{j=1}^{i} W_j e^{\{\frac{c_j}{c_{i+1}}\mu t\}} \frac{1}{(n-i-1)!} \int_0^{t\mu} e^{(d_j y)} y^{(n-i-1)} dy + \sum_{k=0}^{n-i-1} e^{(-\mu t)} \frac{(\mu t)^k}{k!}.$$

where $c_j = n - j + 1$, $d_j = \frac{i+1-j}{n-i}$ and $w_j = \frac{1}{n-j+1} \frac{n!}{(n-i)!} \frac{(-1)^{i-j}}{(j-1)!(i-j)!}$

Substituting theorem 4 into (3.15), the opportunistic cooperative beamforming using i relays can be shown as follow:

$$\begin{aligned} P_{out,Oc-BF-i} &= \int_0^{\delta} P\{T_{M-i-1} < (\delta - w)\} f_W(w) dw \\ &= \int_0^{\delta} \{1 - P\{T_{M-i-1} > (\delta - w)\}\} f_W(w) dw \end{aligned} \tag{3.16}$$

where $w = (1-\alpha)\gamma\alpha_0 \sim Exp(\lambda_0)$ and $Z_i \sim Exp(\lambda_1 + \lambda_2)$.

The numerical simulation is given in Fig. 3.3. and it provides that the performance gap can be reduced by using more best relays. However, the gap is reduced less when using more best relays to help transmission. Thus, we should take suitable relay number to achieve the target of performance.

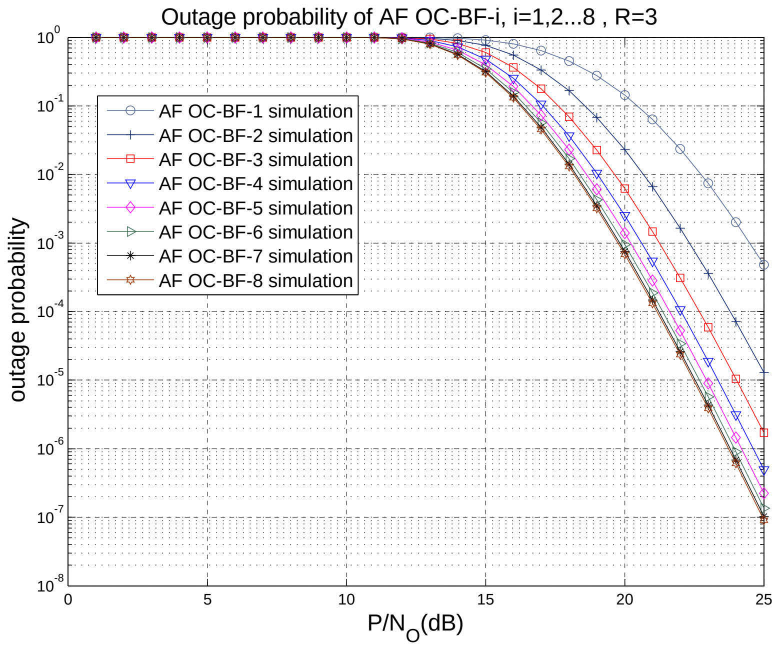

Figure 3.3: Outage performance of AF OC-BF-i, ($i = 1, 2 \cdots 8$) (M=8, R=3, $\alpha = 0.5$).

3.2 DF Protocol

The outage probability for DF protocol is shown as

$$P_{out} = \sum_{i=0}^{M} P\{\frac{1}{2}log(1 + SNR) < R||\mathcal{D}(\mathcal{S})| = i\}P\{|\mathcal{D}(\mathcal{S})| = i\} \tag{3.17}$$

The $P\{|\mathcal{D}(\mathcal{S})| = i\}$ is the probability of decoding size, and $P\{\frac{1}{2}log(1+SNR) < R||\mathcal{D}(\mathcal{S})| = i\}$ is the conditional outage probability when the size of decoding set is equal to i. The probability of relay decoded correctly is given by

$$P_{relay_i} = P\{\frac{1}{2}log(1 + (1 - \alpha)\gamma\alpha_i) > R\} = e^{-\lambda_0\delta} \tag{3.18}$$

where $\alpha_i = |h_{s,r_i}|^2$ is exponential distribution with parameter λ_0. Thus, the probability of decoding set size can be given by

$$P(|\mathcal{D}(\mathcal{S})|) = C^M_{|\mathcal{D}\mathcal{S}|}(e^{-\lambda_0\delta})^{|\mathcal{D}(\mathcal{S})|}(1 - e^{-\lambda_0\delta})^{M-|\mathcal{D}(\mathcal{S})|}. \tag{3.19}$$

To simplify the analysis, we only discuss the conditional outage probability in following case. The outage probability for DF protocol by equation(3.17).

3.2.1 Opportunistic Relaying (O-R)

The received SNR of opportunistic relaying case is given by

$$\begin{aligned} SNR_{O-R,DF} &= \frac{P_s|h_{s,d}|^2}{N_0} + \frac{\max_{i\epsilon\mathcal{D}(\mathcal{S})} P_r|h_{i,d}|^2}{N_0} \\ &= (1-\alpha)\gamma\alpha_0 + \alpha \max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\beta_i \end{aligned}$$

To simplify the following discussion, we define the order static set $\{X_1, X_2, \cdots X_{|\mathcal{D}(\mathcal{S})|}\}$ with order $\{X'_{|\mathcal{D}(\mathcal{S})|} > X'_{|\mathcal{D}(\mathcal{S})|-1} > X'_2, \cdots > X'_1\}$ The conditional outage probability for opportunistic relaying is

$$\begin{aligned} P_{conditional,O-R} &= P\{SNR < \delta\} = P\{(1-\alpha)\gamma\alpha_0 + \alpha \max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\beta_i\} \\ &= \int_0^{\delta} P\{X'_{\mathcal{D}(\mathcal{S})} < \delta - w\} f_W(w)dw \\ &= \sum_{i=0}^{|\mathcal{D}|} (-1)^i C_i^{|\mathcal{D}\mathcal{S}|} \lambda_0 e^{-\lambda_2 \delta i} \{\frac{(1 - e^{((\lambda_0-\lambda_2)k)\delta})}{(\lambda_0-\lambda_2)k}\} \end{aligned} \quad (3.20)$$

where $X_i = \alpha\gamma\beta_i, i\epsilon\mathcal{D}(\mathcal{S})$ and $X_i \sim Exp(\lambda_2)$,$\lambda_2 = 1/(\alpha\gamma)$

3.2.2 Cooperative Beamforming (Co-BF)

The received SNR of cooperative beamforming case is given by

$$\begin{aligned} SNR_{Co-BF,DF} &= \frac{P_s|h_{s,d}|^2}{N_0} + \frac{\sum_{i,j\epsilon\mathcal{D}(\mathcal{S})} P_r\{|h_{i,d}|^2\}}{N_0} \\ &= (1-\alpha)\gamma\alpha_0 + \alpha \sum_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma(\beta_i) \end{aligned}$$

The conditional outage probability for cooperative beamforming is

$$\begin{aligned} P_{conditional,CO-BF} &= P\{(1-\alpha)\gamma\alpha_0 + \alpha \sum_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\{\beta_i\}\} \\ &= \int_0^\delta P\{\sum_{i\epsilon\mathcal{D}(\mathcal{S})} X_i < \delta - w\} f_W(w)dw \\ &= \int_0^\delta P\{Q < \delta - w\} f_W(w)dw \end{aligned} \tag{3.21}$$

where Q is sum of $|\mathcal{D}(\mathcal{S})|$ exponential random variables and Q is the gamma distribution $\Gamma(|\mathcal{D}(\mathcal{S})|, 1/\lambda)$

3.2.3 Opportunistic Cooperative Beamforming Using Two Relays (OC-BF-2)

The received SNR of (OC-BF-2) is given by

$$\begin{aligned} SNR_{OC-BF,DF} &= \frac{P_s|h_{s,d}|^2}{N_0} + \frac{\max_{i\epsilon\mathcal{D}(\mathcal{S})} P_r\{|h_{r_i,d}|^2 + |h_{r_j,d}|^2\}}{N_0} \\ &= (1-\alpha)\gamma\alpha_0 + \alpha \max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma(\beta_i + \beta_j) \end{aligned}$$

The conditional outage probability for opportunistic relaying is

$$\begin{aligned} P_{conditional,OC-BF-2} &= P\{(1-\alpha)\gamma\alpha_0 + \alpha \max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\{\beta_i + \beta_j\}\} \\ &= \int_0^\delta P\{X'_{|\mathcal{D}(\mathcal{S})|} + X'_{|\mathcal{D}(\mathcal{S})|-1} < \delta - w\} f_W(w)dw \end{aligned} \tag{3.22}$$

By using theorem 3, we can obtain the conditional outage probability in equation (3.23).

3.2.4 Opportunistic Cooperative Beamforming Using i Relays (OC-BF-i)

The conditional outage of (OC-BF-i) is shown as

$$\begin{aligned} P_{conditional,OC-BF-i} &= P\{(1-\alpha)\gamma\alpha_0 + \alpha \sum_{|\mathcal{D}(\mathcal{S})-i-1|}^{|\mathcal{D}(\mathcal{S})|} \gamma\{\beta_i\}\} \\ &= \int_0^{\delta} P\{\sum_{k=|\mathcal{D}(\mathcal{S})-i-1|}^{|\mathcal{D}(\mathcal{S})|} X_k^{'} < \delta - w\} f_W(w) dw \end{aligned} \tag{3.23}$$

By using the theorem 4, we can obtain the $P\{\sum_{k=|\mathcal{D}(\mathcal{S})-i-1|}^{|\mathcal{D}(\mathcal{S})|} X_k^{'} > \delta - w\}$. Thus, substituting equation (3.23) into equation (3.17), the outage probability of (OC-BF-i) for DF protocol can be obtained.

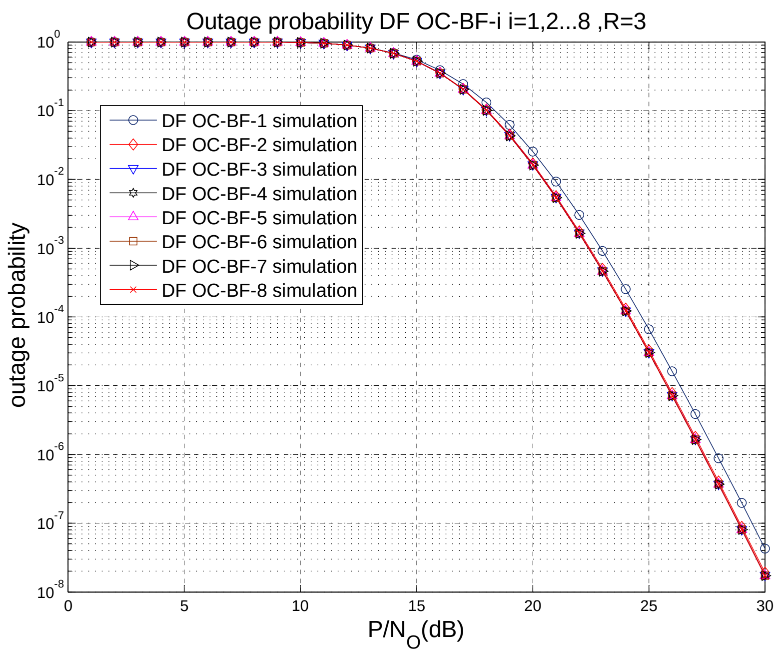

Figure 3.4: Outage performance of DF OC-BF-i, ($i = 1, 2 \cdots 6$) (M=8, R=3, $\alpha = 0.5$).

3.3 Cooperative Diversity and SNR Offset Analysis

From previous discussion of outage probability for DF and AF protocols, we will analyze cooperative diversity and SNR offset in OC-BF-i. The diversity gain can be defined as

$$\lim_{SNR\to\infty} \frac{\log\left(P_{out}\{(SNR, R)\}\right)}{\log\{(SNR)\}} = d \tag{3.24}$$

Thus, the outage probability in high SNR regime can be expressed as

$$P_{out} \approx C \cdot (SNR)^{-d} \tag{3.25}$$

where d is the diversity gain and C is the SNR offset

3.3.1 Analysis Diversity and Offset Gain for Opportunistic Cooperative Beamforming {OC-BF-i}

AF protocol:

From equation (3.16), the outage probability general from in OC-BF-i is sum of largest i out of M exponential random variables. Thus,

$$\begin{aligned} P_{out,Oc-BF-i} &= P\{\gamma\alpha_0 + \sum_{i=M-i-1}^{M} Z_i' < \delta\} \\ &= \int_0^{\delta} P\{T_{M-i-1} < (\delta - w)\} p_W(w) dw \end{aligned} \tag{3.26}$$

where $T_{M-i-1} = Z_M' + Z_{M-1}' + \cdots Z_{M-i-1}'$

From [15], we can obtain the joint probability density function for i out of M order statistics $f_{Z'_M Z'_{M-1}\cdots Z'_{M-i-1}}(Z'_M, Z'_{M-1}, \cdots Z'_{M-i-1})$

$$
\begin{aligned}
& f_{Z'_M Z'_{M-1}\cdots Z'_{M-i-1}}(Z'_M, Z'_{M-1}, \cdots Z'_{M-i-1}) \\
&= \frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^i e^{-(\lambda_1+\lambda_2)(Z'_M+Z'_{M-i-1}\cdots Z'_{M-i-1})}(1-e^{-(\lambda_1+\lambda_2)Z'_{M-i-1}})^{M-i}
\end{aligned}
$$

where $Z'_M > Z'_{M-1} > \cdots > Z'_{M-i-1}$ and $U = \delta - w$

$$
\begin{aligned}
& P\{Z'_M + Z'_{M-1} + \cdots Z'_{M-i-1} < U\} \\
&= \int_0^{\frac{U}{i}} \int_{Z'_{M-i-1}}^{\frac{U-Z'_{M-i-1}}{i-1}} \cdots \int_{Z'_{M-i}}^{U-Z'_{M-i-1}-Z'_{M-i}-\cdots Z'_M} f_{Z'_M Z'_{M-1}\cdots Z'_{M-i-1}}(Z'_M, Z'_{M-1}, \cdots Z'_{M-i-1}) \\
& dZ'_M dZ'_{M-1} \cdots dZ'_{M-i-1} \\
&= \int_0^{\frac{U}{i}} \int_{Z'_{M-i-1}}^{\frac{U-Z'_{M-i-1}}{i-1}} \cdots \int_{Z'_{M-i}}^{U-Z'_{M-i-1}-Z'_{M-i}-\cdots Z'_M} \\
& \times \frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^i e^{-(\lambda_1+\lambda_2)(Z'_M+Z'_{M-i-1}\cdots Z'_{M-i-1})} \\
& \times (1-e^{-(\lambda_1+\lambda_2)Z'_{M-i-1}})^{M-i} dZ'_M dZ'_{M-1} \cdots dZ'_{M-i-1}
\end{aligned} \tag{3.27}
$$

We assume $\lambda = 1/\gamma$ and the the offset gain can be expressed as

$$
\begin{aligned}
& \lim_{SNR\longrightarrow\infty} \frac{P_{out}}{SNR^{-(M+1)}} = \lim_{\lambda\longrightarrow 0} \frac{P_{out}}{\lambda^{M+1}} \\
&= \lim_{\lambda\longrightarrow 0} \frac{\int_0^{\delta} P\{Z'_M + Z'_{M-1} + \cdots Z'_{M-i-1} < (\delta - w)\}\lambda_0 e^{-\lambda_0 w} dw}{\lambda^{M+1}} \\
&= \int_0^{\delta} \lim_{SNR\longrightarrow\infty} \frac{P\{Z'_M + Z'_{M-1} + \cdots Z'_{M-i-1} < (\delta - w)\}\lambda_0 e^{-\lambda_0 w} dw}{\lambda^{M+1}} \\
&= \int_0^{\delta} \lim_{SNR\longrightarrow\infty} \int_0^{\frac{U}{i}} \int_{Z'_{M-i-1}}^{\frac{U-Z'_{M-i-1}}{i-1}} \cdots \int_{Z'_{M-i}}^{U-Z'_{M-i-1}-Z'_{M-i}-\cdots Z'_M} \\
& \times \frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^i e^{-(\lambda_1+\lambda_2)(Z'_M+Z'_{M-i-1}\cdots Z'_{M-i-1})} \\
& \times (1-e^{-(\lambda_1+\lambda_2)Z'_{M-i-1}})^{M-i} dZ'_M dZ'_{M-1} \cdots dZ'_{M-i-1} \lambda_0 e^{-\lambda_0 w} dw/\lambda^{M+1}
\end{aligned}
$$

Submitting joint probability into equation(3.28), the above equation can be reduced by L'Hospital's rule. Thus, the offset gain formula can be expressed as

$$\int_0^{\delta}\int_0^{\frac{U}{i}}\int_{Z'_{M-i-1}}^{\frac{U-Z'_{M-i-1}}{i-1}}\cdots\int_{Z'_{M-i}}^{U-Z'_{M-i-1}-Z'_{M-i}-\cdots Z'_M}$$
$$\times\frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^M(Z'_{M-i-1})^{M-i}dZ'_M dZ'_{M-1}\cdots dZ'_{M-i-1}\lambda_0 dw \quad (3.28)$$

In order to change the range of integral in equation (3.28), we set

$$\left\{\begin{array}{c} t_M = Z'_M - Z'_{M-1} \\ t_{M-1} = Z'_{M-1} - Z'_{M-2} \\ \vdots \\ t_{M-i-1} = Z'_{M-i-1} \end{array}\right\} \quad (3.29)$$

$$\int_0^{\delta}\int_0^{\frac{U}{i}}\int_{Z'_{M-i-1}}^{\frac{U-Z'_{M-i-1}}{i-1}}\cdots\int_{Z'_{M-i}}^{U-Z'_{M-i-1}-Z'_{M-i}-\cdots Z'_M}$$
$$\times\frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^M(Z'_{M-i-1})^{M-i}dZ'_M dZ'_{M-1}\cdots dZ'_{M-i-1}\lambda_0 dw$$
$$=\int_0^{\delta}\int_0^{\frac{U}{i}}\int_0^{\frac{U-(M-i-1)t_{(M-i-1)}}{i-1}}\cdots\int_0^{U-(M-i-1)t_{(M-i-1)}-(M-i)t_{(M-i)}-\cdots(M)t_{(M)}}$$
$$\times\frac{M!}{(M-i)!}(\lambda_1+\lambda_2)^M(t_{M-i-1})^{M-i}dt_M dt_{M-1}\cdots dt_{M-i-1}\lambda_0 dw$$

By using the formula in Appendix A, we can obtain the offset gain as

$$\lim_{SNR\longrightarrow\infty}\frac{P_{out}}{SNR^{-(M+1)}}=\int_0^{\delta}\frac{(\delta-w)^M}{i!i^{M-i}}(\lambda_1\lambda_2)^M\lambda_0 dw$$
$$=\frac{(\lambda_1+\lambda_2)^M\lambda_0}{i!i^{M-i}}\frac{\delta^{M+1}}{M+1}=\{\frac{1}{(1-\alpha)}\}\{\frac{1}{1-\alpha}+\frac{1}{\alpha}\}^M\frac{(\lambda\delta)^{M+1}}{i!i^{M-i}}\frac{1}{M+1} \quad (3.30)$$

From above expression, we can obtain the diversity $M+1$ and offset gain $\{\frac{1}{(1-\alpha)}\}\{\frac{1}{1-\alpha}+\frac{1}{\alpha}\}^M\frac{(\delta)^{M+1}}{i!i^{M-i}}\frac{\delta^{M+1}}{M+1}$.

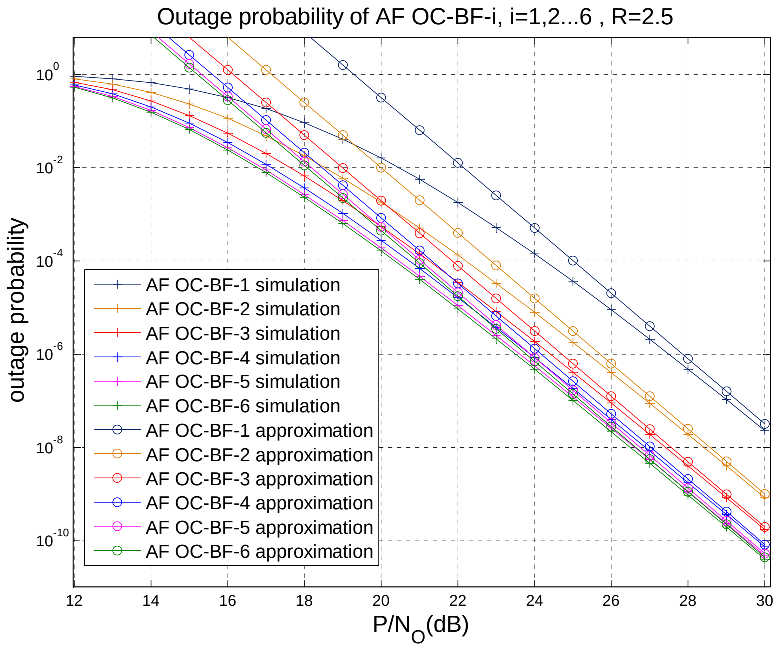

Figure 3.5: Offset and diversity analysis for AF protocol, (M=6, R=2.5, $\alpha = 0.5$)

DF protocol:

Because the conditional outage for DF protocol is similar as outage probability for AF protocol. By using the similar analysis method, we can obtain the SNR offset in high SNR regime can be obtain as

$$\sum_{|\mathcal{D}(\mathcal{S})|} \frac{C^{M}_{|\mathcal{D}(\mathcal{S})|}}{|\mathcal{D}(\mathcal{S})|+1}\{\frac{1}{1-\alpha}\}\{\frac{1}{\alpha}\}^{M}(\frac{\delta}{\gamma})^{M+1}\frac{1}{i!i^{|\mathcal{DS}|-i}} \tag{3.31}$$

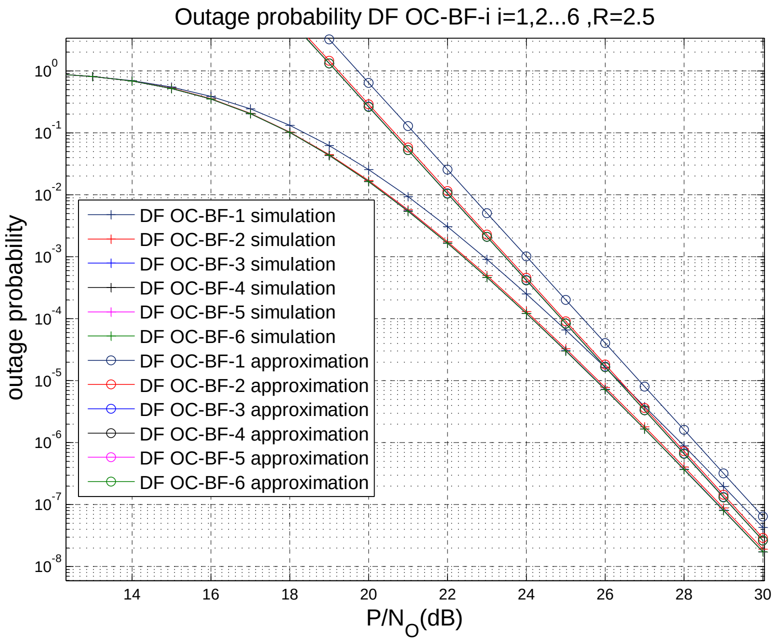

Figure 3.6: Offset and diversity analysis for DF protocol, (M=6, R=2.5, $\alpha = 0.5$)

Chapter 4

Cooperative ARQ Scheme for Decode-and-Forward and Amplify-and-Forward Protocols

We extend the results in the previous section to develop ARQ schemes for DF and AF protocols, and analyze the outage performance for corresponding cooperative ARQ scheme. Here, we refer to the broadcasting phase and the relay phase as the cooperative phase, and the ARQs that follow, as the ARQs phases. Here, we proposed two phase (TP) and one phase (OP) ARQ scheme for DF and AF protocols. The two phase ARQ scheme is means that the cooperative phase with source broadcasting phase and relaying phase. Another one in cooperative phase only has source broadcasting phase without relaying phase. Beside, we also proposed several types for DF and AF protocols and the detail discussion is given in following section. The following type of cooperative ARQ scheme classify as shown in Fig4.1

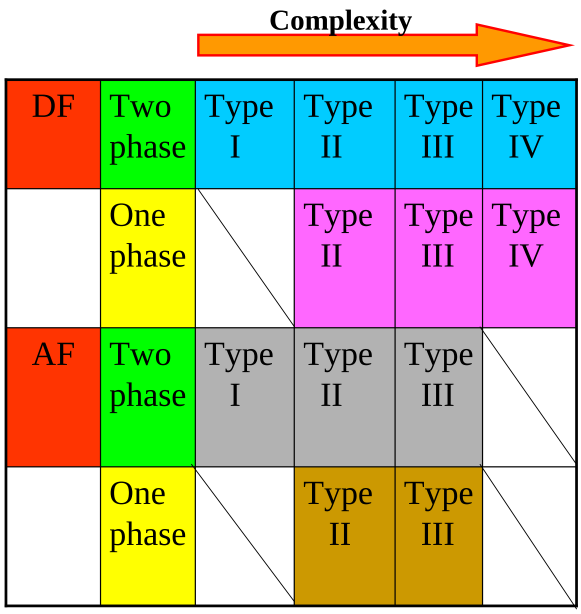

Figure 4.1: The classify of cooperative ARQ scheme

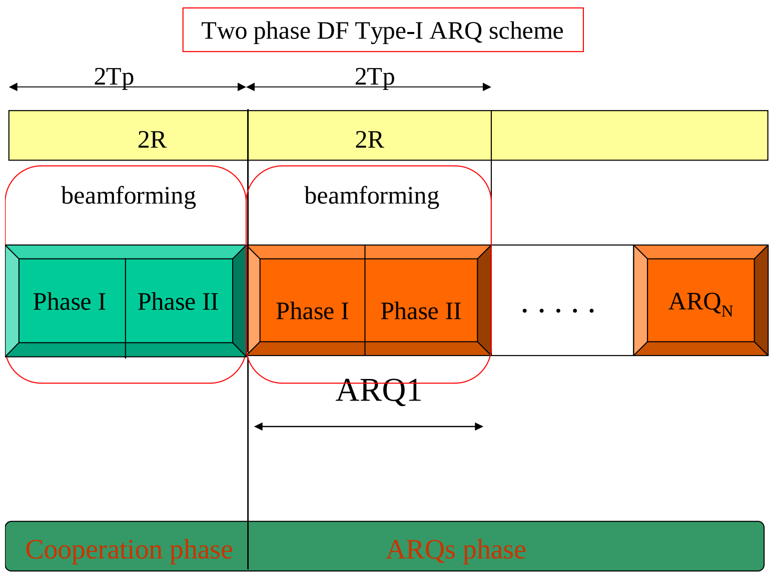

Figure 4.2: TP DF Type-I ARQ scheme

4.1 TP DF ARQ Scheme

The cooperative phase obtains source broadcasting phase and the relaying phase. The cooperative phase takes two times transmission time to transmit signal to destination. At the destination, the receiver uses (MRC) to combine two phase signals.

4.1.1 TP DF Type-I ARQ Scheme

To reduce the complexity of relay, we assume that the relay is memoryless. Each relay does not keep the received signal in previous phase. Thus, each ARQ phase including source broadcasting phase and relaying phase. Especially, the cooperative phase and each ARQ phase take two times transmission. At the destination, the receiver use MRC to combine two phase signal. The TP DF type-I ARQ scheme is proposed as in Fig.4.2

Because the channel between each ARQ phase and cooperative phase are independent. Thus, the outage probability after N times ARQ phases is given by

$$P_{out,N} = \{P_{out}\}^{(N+1)} \tag{4.1}$$

where P_{out} is the outage probability for cooperative phase with two phase combing equation(3.17).

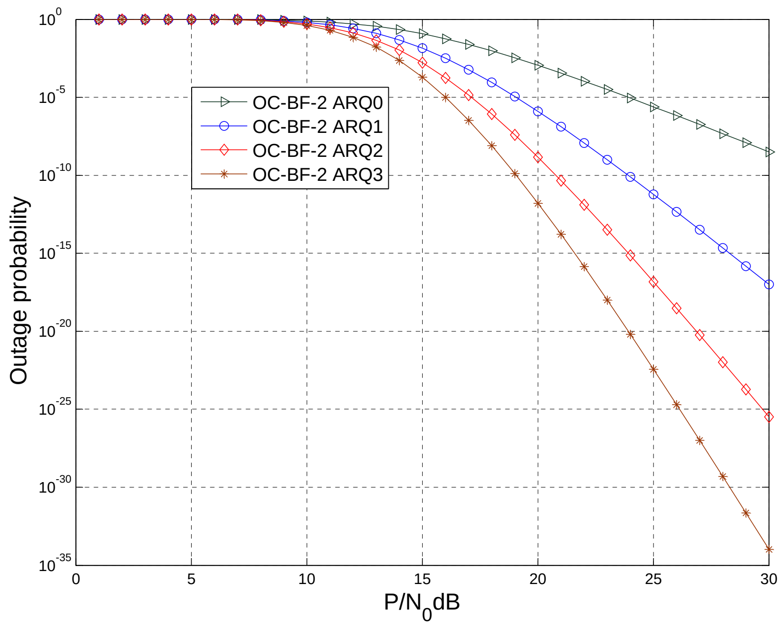

Figure 4.3: Outage probability for TP DF type-I OC-BF-2 in different ARQ times, $[M = 5, R = 2, \alpha = 0.5]$

4.1.2 TP DF Type-II ARQ Scheme

The cooperative phase includes the broadcasting phase and relaying phase so it takes two times transmission time (T_p). In the broadcasting phase, the source broadcasts the signal to all relays and destination. In relaying phase, the decoded correctly relay transmits signal to destination and the receiver uses the MRC to combine two phase received signal at the destination. Different from DF type-I scheme, the relays can keep the information in cooperative phase. Thus , each ARQ phase uses the same relay as the cooperative phase to re-transmission as shown in Fig.4.4.

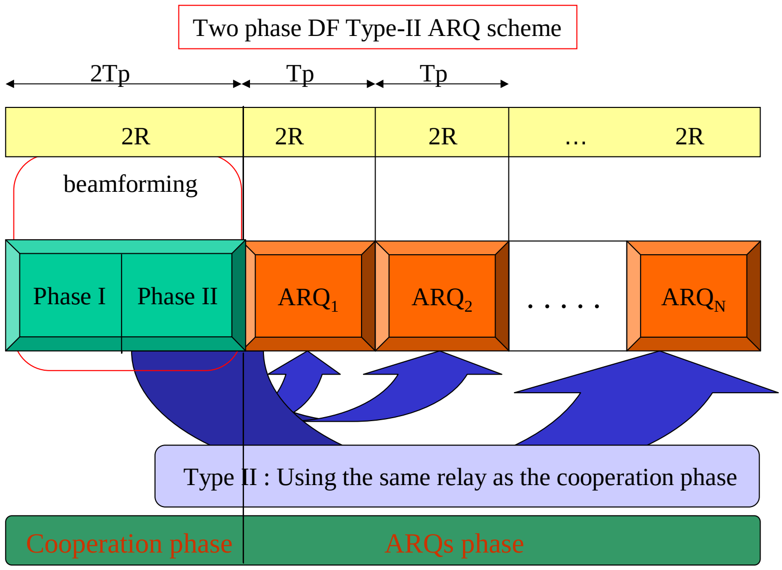

Figure 4.4: TP DF type-II ARQ scheme

Now, we describes the situation of different size of decoding set. If $|\mathcal{D}(\mathcal{S})| > 1$, it is simply equal to relaying phase of OC-BF, but in sequel ARQs phase it uses the same relay as the relaying phase of cooperation phase. If not, the source will re-broadcast the signal in each ARQ phase, until the $|\mathcal{D}| \geq 1$. Then, the following ARQ phase will select the relay nodes and retransmits signal in the similar way as relaying phase. The relay nodes in each ARQ is the same as cooperative phase. Especially, the cooperative phase includes two phases and each ARQ phase includes one phase transmission.

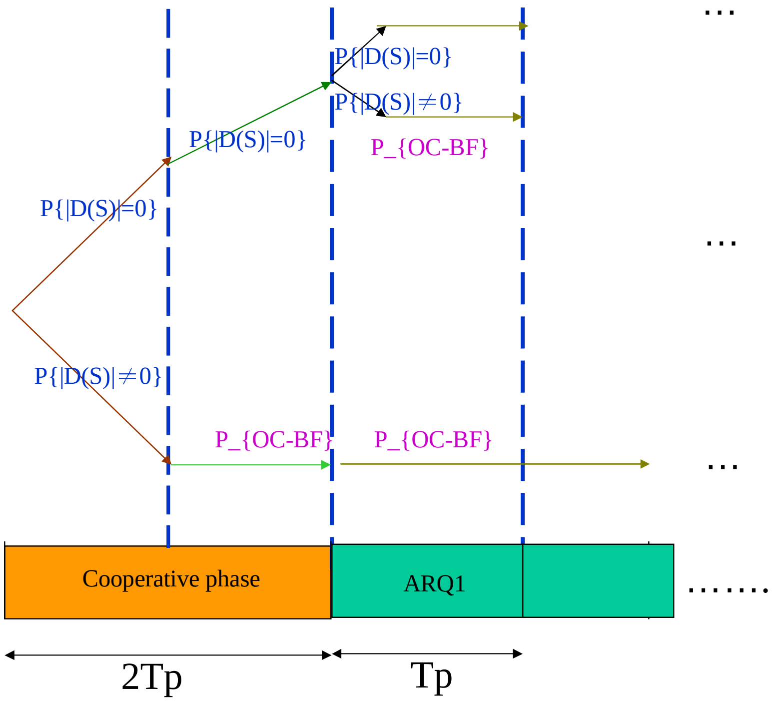

Figure 4.5: Tree diagram of TP DF type-II ARQ.

To characterize the outage probability of the above type II ARQ scheme, we consider the outage events in $|\mathcal{D}(\mathcal{S})|$ of OC-BF separately. In case of $|\mathcal{D}(\mathcal{S})| = 0$, the source will directly retransmit the signal. When the size of decoding set is equal to zeros the corresponding outage probability of two phase combing is given by

$$P_{s_2,|\mathcal{D}(\mathcal{S})|=0} = P_2(R, SNR||\mathcal{D}(\mathcal{S})| = 0)P(|\mathcal{D}(\mathcal{S})| = 0) \tag{4.2}$$

where $P(|\mathcal{D}(\mathcal{S})| = 0)$ can be obtained by equation (3.19), and the conditional outage probability with two phase combing $P_2(R, SNR||\mathcal{D}(\mathcal{S})| = 0)$ is defined as :

$$P_2(R, SNR||\mathcal{D}|) \triangleq \left\{ \begin{array}{cc} P\{\frac{1}{2}\log(1 + \frac{(P_s|h_{s,d}|^2 + P_s|h_{s,d}|^2)}{N_0}) < R\} & , |\mathcal{D}| = 0 \\ P\{\frac{1}{2}\log(1 + \frac{(P_s|h_{s,d}|^2 + P_i|h_{i,d}|^2)}{N_0}) < R\} & , |\mathcal{D}| = 1 \\ P\{\frac{1}{2}\log(1 + \frac{P_s|h_{s,d}|^2}{N_0} + max_{i,j\varepsilon\mathcal{D}(\mathcal{S})}\frac{P_r(|h_{i,d}|^2 + |h_{j,d}|^2)}{N_0}) < R\} & , |\mathcal{D}| \geq 2 \end{array} \right\}. \tag{4.3}$$

When the size of decoding set is equal to zero, the outage probability with one phase combing is $P_{s_1,|\mathcal{D}(\mathcal{S})|=0}$ in ARQ phase defined as

$$P_{s_1,|\mathcal{D}(\mathcal{S})|=0} \triangleq P_1(R, SNR||\mathcal{D}(\mathcal{S})| = 0)P(|\mathcal{D}(\mathcal{S})| = 0) \tag{4.4}$$

where the conditional outage probability with one phase transmission $P_1(R, SNR||\mathcal{D}(\mathcal{S})| = 0)$ is given by

$$P_1(R, SNR||\mathcal{D}|) \triangleq \left\{ \begin{array}{cc} P\{\frac{1}{2}\log(1+\frac{P_s(|h_{s,d}|^2)}{N_0}) < R\} & ,|\mathcal{D}| = 0 \\ P\{\frac{1}{2}\log(1+\frac{P_r(|h_{i,d}|^2)}{N_0}) < R\} & ,|\mathcal{D}| = 1 \\ P\{\frac{1}{2}\log(1+max_{i,j\varepsilon\mathcal{D}(\mathcal{S})}\frac{P_r(|h_{i,d}|^2+|h_{j,d}|^2)}{N_0}) < R\} & ,|\mathcal{D}| \geq 2 \end{array} \right\}. \tag{4.5}$$

We can use equation (4.5) and (4.5) to re-write the outage probability for cooperative phase and it can be shown as follow:

$$\begin{aligned} P_{out,0} &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0} + \{\sum_{i=1}^{M} P_2\{SNR, R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})| = i\}\} \\ &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0} + \sum_{i=1}^{M} A_i^{[2]} \end{aligned} \tag{4.6}$$

where the $P_2\{SNR, R||\mathcal{D}(\mathcal{S})|\}$ is given in equation(4.3) For brevity, we assume $A_i^{[2]}$=$\{P_2\{SNR, R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})| = i\}\}$ to rewrite the expression in equation (4.6). The each ARQ phase is the one phase transmission without source broadcasting. Thus, we also define the $A_i^{[1]} = \{P_1\{SNR, R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})| = i\}\}$ to reduce the outage expression. From Fig.4.5, we can use the tree diagram to analyze the outage probability after one times ARQ and it is shown as follow

$$\begin{aligned} P_{out,1} &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0}\{P_{s_1,|\mathcal{D}(\mathcal{S})|=0}+\{\sum_{i=1}^{M}P_1\{SNR,R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})|=i\}\}\} \\ &+ \{\sum_{i=1}^{M}P_2\{SNR,R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})|=i\}\}P_1 \\ &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0}B_1+\sum_{i=1}^{M}A_i^{[2]}P_1 \end{aligned} \quad (4.7)$$

where $B_1 = \{P_{s_1,|\mathcal{D}(\mathcal{S})|=0}+\sum_{i=1}^{M}P_1\{SNR,R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})|=i\}\} = P_{s_1,|\mathcal{D}(\mathcal{S})|=0}+\sum_{i=1}^{M}A_i^{[1]}$

Here, we also discuss the detail derivation in outage probability after two times ARQ transmission given by

$$\begin{aligned} P_{out,2} &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0}\{P_{s_1,|\mathcal{D}(\mathcal{S})|=0}(P_{s_1,|\mathcal{D}(\mathcal{S})|=0}+\sum_{i=1}^{M}A_i^{[1]})\} \\ &+ P_{s_2,|\mathcal{D}(\mathcal{S})|=0}\{\sum_{i=1}^{M}A_i^{[1]}P_1\}+\sum_{i=1}^{M}A_i^{[2]}P_1^2 \\ &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0}\{P_{s_1,|\mathcal{D}(\mathcal{S})|=0}^2+P_{s_1,|\mathcal{D}(\mathcal{S})|=0}\sum_{i=1}^{M}A_i^{[1]}+\sum_{i=1}^{M}A_i^{[1]}P_1\} \\ &+ \sum_{i=1}^{M}A_i^{[2]}P_1^2 \\ &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0}B_2+\sum_{i=1}^{M}A_i^{[2]}P_1^2 \end{aligned} \quad (4.8)$$

where $B_2 = P_{s_1,|\mathcal{D}(\mathcal{S})|=0}B_1+\sum_{i=1}^{M}A_i^{[1]}P_1$. The P_1 can summarize in different case as shown below:

$$P_1 \triangleq \left\{ \begin{array}{c} P\{(1-\alpha)\gamma\beta_i<\delta\},\{\text{OR case}\} \\ P\{(1-\alpha)\gamma(\beta_i+\beta_j)<\delta\},\{\text{OC-BF-2 case}\} \\ P\{(1-\alpha)\gamma\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|}\beta_i<\delta\},\{\text{Co-BF case}\} \end{array} \right\} \quad (4.9)$$

By using the above two expressions, the formula of the outage probability after N times cooperative ARQ phase can use the tree diagram (Fig.4.5) to obtain ARQ outage probability given by

$$P_{out,N} = P_{s_2,|\mathcal{D}(\mathcal{S})|=0} B_N + (\sum_{i=1}^{M} A_i^{[2]}) P_1^N \tag{4.10}$$

where $B_N = B_{N-1} P_{s_1,|\mathcal{D}(\mathcal{S})|=0} + (\sum_{i=1}^{M} A_i^{[1]}) P_1^{N-1}$ and $B_0 = 1$ and $P_1^{-1} = 1$.

4.1.3 TP DF Type-III ARQ Scheme

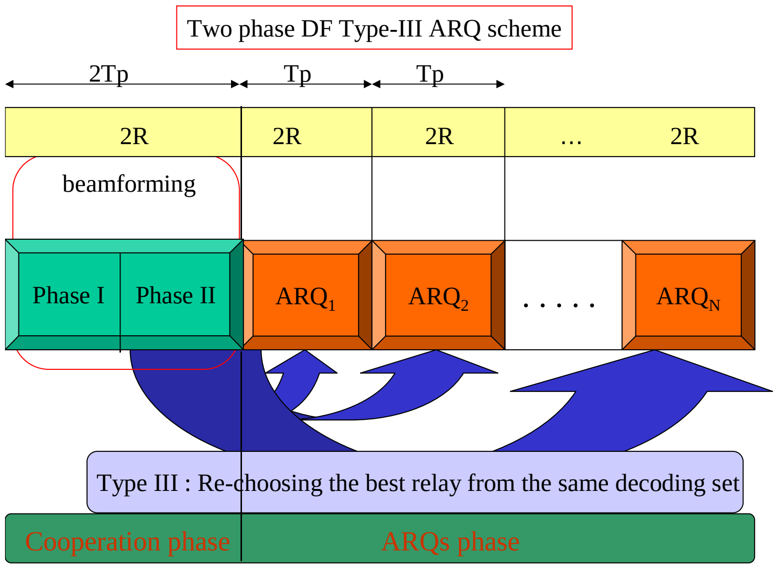

Figure 4.6: TP DF type-III ARQ scheme

Here, we proposed the type-III ARQ scheme and the relay in each ARQ phase is chosen from the decoding that obtains in cooperative phase. Thus, the decoding set must be keep in each ARQ phase. The TP DF type-III ARQ scheme is shown in Fig.4.6. From the analysis of TP DF type-II ARQ scheme, we can modify the outage probability for TP DF type-II formula to TP DF type-III . Thus, the outage probability after N times TP DF type-III ARQ is given by:

$$P_{out,N} = P_{s2,|\mathcal{D}(\mathcal{S})|=0} C_N + (\sum_{i=1}^{M} A_i^{[2]} P_i^N) \tag{4.11}$$

$$P_i \triangleq \left\{ \begin{array}{c} P\{(1-\alpha)\max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma\beta_i < \delta\}, \{\text{OR case}\} \\ P\{(1-\alpha)\max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma(\beta_i + \beta_j) < \delta\}, \{\text{OC-BF case}\} \\ P\{(1-\alpha)\max_{i\epsilon\mathcal{D}(\mathcal{S})} \gamma \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} \beta_i < \delta\}, \{\text{Co-BF case}\} \end{array} \right\} \tag{4.12}$$

where $C_N = C_{N-1} P_{s1,|\mathcal{D}(\mathcal{S})|=0} + (\sum_{i=1}^{M} A_i^{[1]} P_i^{N-1})$,$C_{-1} = 1$ and $P_i^{-1} = 1$.

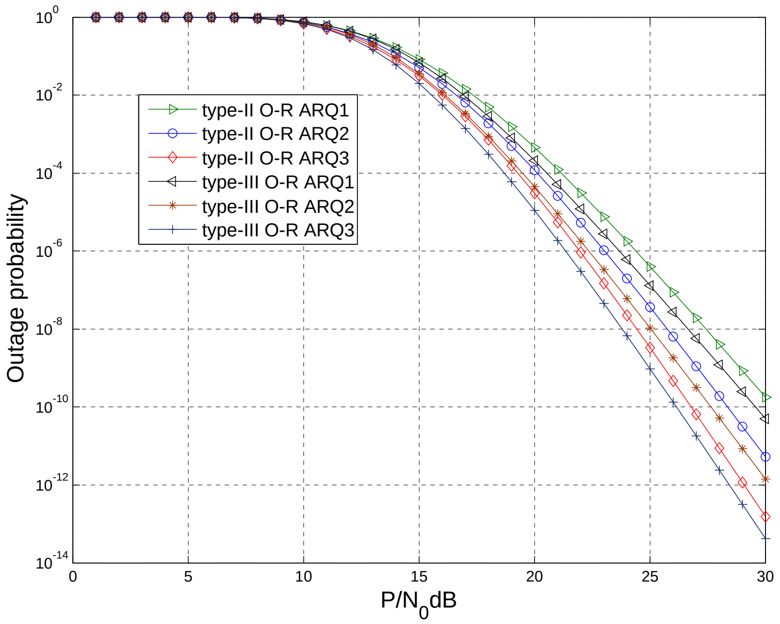

Figure 4.7: Outage probabilities of TP DF type-II and type-III O-R in different ARQ times, $[M = 5, R = 2, \alpha = 0.5]$

From Fig. 4.7 and Fig. 4.8, we can observe that the the cooperative diversity for opportunistic relaying in type II ARQ scheme is equal to type-III ARQ scheme, but there still have some offset between type-II and type-III. However, the ARQ performance of Co-BF can be achieved by OC-BF-2 and the gap is closed to zero by using five relays at rate two. Different from DF TP type-II ARQ scheme, the relay here is chosen from the

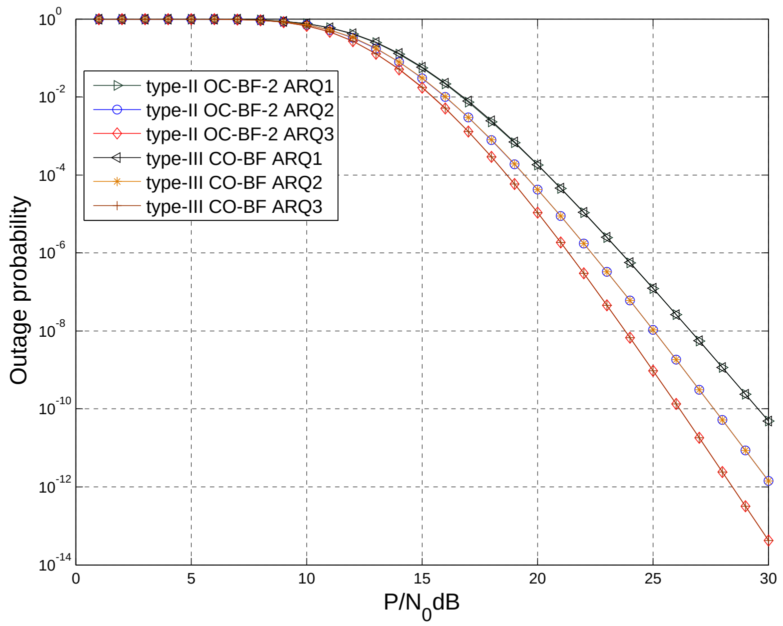

Figure 4.8: Outage probabilities TP DF type-II OC-BF-2 and type-III CO-BF in different ARQ times, $[M = 5, R = 2, \alpha = 0.5]$

same decoding set as cooperative phase rather than using the same relay in cooperative phase. The diversity order of type-III ARQ scheme is dominant by the event $|\mathcal{D}(\mathcal{S})| = 1$ even though other terms can provide higher order term and the outage performance of Co-BF can be achieved by OC-BF-2. Thus, we can expect that the outage probability of OC-BF type-II and OC-BF type-III will coincide with the case of Co-BF TP DF type-III ARQ scheme

4.1.4 TP DF Type-IV ARQ Scheme

According to the discussion of previous section, it can be observed that the cooperative diversity can not grow up even though re-select the best relays in type-III scheme. To overcome this diversity disadvantage, we consider the TP DF type-IV scheme that the size of decoding set will grow up by relaying phase and each ARQ phase. The TP DF type-IV ARQ scheme is shown in Fig.4.9.

In the relaying phase, the relays which are belong to decoding set transmit signal

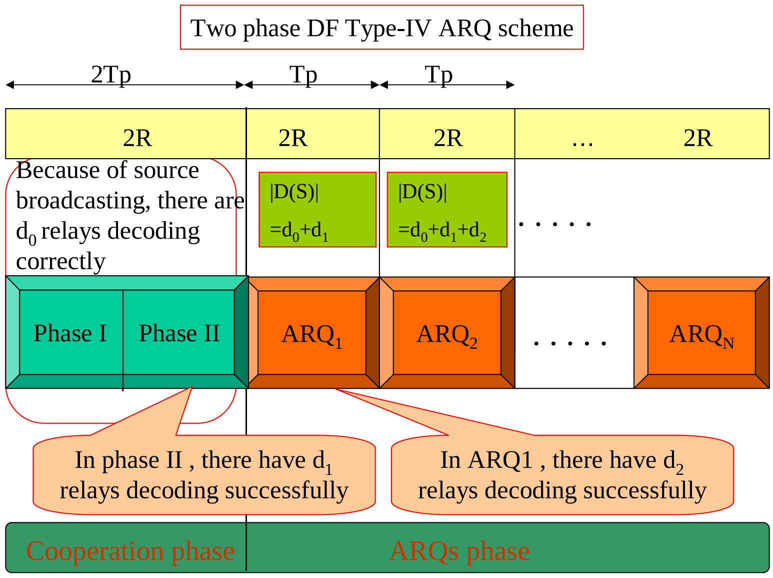

Figure 4.9: TP DF type-IV ARQ scheme

to destination and the remaining relays received signal from this transmission. The received signal in un-decoded correctly relay is given by

$$
\begin{aligned}
y_j &= \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} \sqrt{P_r} w_{i,DF} h_{i,j} x + n_j \\
&= \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} \frac{\sqrt{P_r} h_{i,d}^{\dagger}}{\sqrt{\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2}} h_{i,j} x + n_j \qquad (4.13)
\end{aligned}
$$

where $h_{i,j}$ is the channel between relay i that does decode correctly in source broadcasting phase and relay j that doesn't decoded correctly in source broadcasting phase. $h_{i,d}$ is the channel between relay i that decoded correctly and destination. The received SNR at the relay j is given by

$$
\begin{aligned}
SNR &= \frac{P_r || \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} \frac{\sqrt{P_r} h_{i,d}^{\dagger}}{\sqrt{\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2}} h_{i,j} ||^2}{N_0} \\
&= \alpha\gamma \frac{|| \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} h_{i,d}^{\dagger} h_{i,j} ||^2}{\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2} \qquad (4.14)
\end{aligned}
$$

After relaying phase, the probability of relay j can not be decoded is show as follow:

$$\begin{aligned}
P\{SNR < \delta\} &= P\{||\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} h_{i,d}^{\dagger} h_{i,j}||^2 < \lambda_2 \delta (\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2)\} \\
&= \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} P\{||\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} h_{i,d}^{\dagger} h_{i,j}||^2 < \lambda_2 \delta (\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |h_{i,d}|^2) | h_{1,d} h_{2,d} \cdots h_{|\mathcal{D}(\mathcal{S})|,d}\} \\
&\quad \times f(h_{1,d}) f(h_{2,d}) \cdots f(h_{|\mathcal{D}(\mathcal{S})|,d}) d_{h_{1,d}} d_{h_{2,d}} \cdots d_{h_{|\mathcal{D}(\mathcal{S})|,d}} \qquad (4.15)
\end{aligned}$$

where we assume that $a_i = h_{i,d} \sim CN(0,1)$, $a_i^{\dagger} = h_{i,d}^{\dagger} \sim CN(0,1)$ and $|a_i|^2 \sim Exp(1)$ From the above expression, it condition on overall channel between successfully decoded relays to destination. Thus, the term $\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} h_{i,d}^{\dagger} h_{i,j}$ that condition on overall channel between successfully decoded relays to destination is complex gaussian distribution with zero mean variance $\sigma^2 = \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |a_i|^2$. We also assume that the $Z = |\sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} h_{i,d}^{\dagger} h_{i,j}|^2$ is exponential distribution with parameter $s = 1/\sigma^2$ and $u = \sum_{i=1}^{|\mathcal{D}(\mathcal{S})|} |a_i|^2$, $s \cdot u = 1$. The equation (4.15).can be reduced to

$$\begin{aligned}
P\{SNR < \delta\} &= \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} P\{Z < \lambda \delta u | a_1, a_2 \cdots a_{|\mathcal{D}(\mathcal{S})|}\} d_{a_1} \cdots d_{a_{|\mathcal{D}(\mathcal{S})|}} \\
&= (1 - e^{-\lambda_2 \delta}) \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} d_{a_1} \cdots d_{a_{|\mathcal{D}(\mathcal{S})|}} \\
&= 1 - e^{-\lambda_2 \delta} \qquad (4.16)
\end{aligned}$$

The successfully decoded probability of the relay that un-decoded in previous phase is equal to $e^{-\lambda_2 \delta}$. The following paragraph, we analyze the cooperative TP DF type-IV ARQ scheme by using the tree diagram as shown Fig. 4.10. Here, we define some parameter to reduce the expression of DF TP type-IV outage probability. We assume that d_0 is the the increased number of size of the decoding set by source broadcasting and d_1 is the increased number of the decoding set size after relaying phase. The $d_i, i = 2, 3 \cdots$ is the increased number of decoding set size after ARQ_{i-1} phase. The cooperative outage probability for type IV ARQ scheme is shown as bellow:

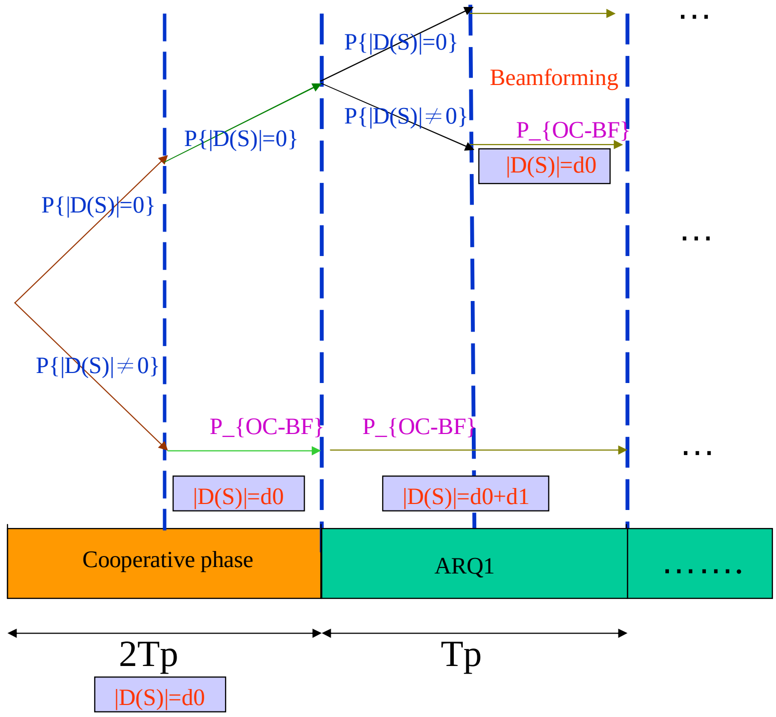

Figure 4.10: Tree diagram for TP DF type-III.

$$
\begin{aligned}
P_{out,0} &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0} + \sum_{d_0=1}^{M} P_2\{R, SNR||\mathcal{D}(\mathcal{S})| = d_0\} P\{|\mathcal{D}(\mathcal{S})| = d_0\} \\
&= P_{s_2,|\mathcal{D}(\mathcal{S})|=0} + \sum_{d_0=1}^{M} P_{2,\mathcal{D}(\mathcal{S})|=d_0} P_{d_0} \qquad (4.17)
\end{aligned}
$$

where the $P_{s_2,|\mathcal{D}(\mathcal{S})|=0}$ is given in equation (4.2) and $P_2\{R, SNR||\mathcal{D}(\mathcal{S})| = d_0\} = P_{2,\mathcal{D}(\mathcal{S})|=d_0}$ is given in equation (4.3) The $P_{d_0} = P\{|\mathcal{D}(\mathcal{S})| = d_0\}$ is given by equation(3.19). By using the tree diagram as shown in Fig.4.10, we can obtain the outage probability after N times TP DF type-IV ARQ scheme is given by:

$$
\begin{aligned}
P_{out,N} &= P_{s_2,|\mathcal{D}(\mathcal{S})|=0} D_N + \sum_{d_0=1}^{M} \sum_{d_1=0}^{M-d_0} \cdots \sum_{d_N=0}^{M-d_0-d_1\cdots-d_{N-1}} P_{2,|\mathcal{D}(\mathcal{S})|=d_0} P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1)} \cdots \\
&\times P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1+\cdots d_N)} P_{d_0} P_{d_1} \cdots P_{d_N} \qquad (4.18)
\end{aligned}
$$

where

$$\left\{\begin{array}{cr} D_0 = 1, & N=0 \\ D_1 = P_{s_1,|\mathcal{D}(\mathcal{S})|=0} + \sum_{d_0=1}^{M} P_{1,|\mathcal{D}(\mathcal{S})|=d_0} P_{d_0}, & N=1 \\ \vdots & \\ D_N = P_{s_1,|\mathcal{D}(\mathcal{S})|=0} D_{N-1} + \sum_{d_0=1}^{M} \sum_{d_1=0}^{M-d_0} \cdots \sum_{d_N=0}^{M-d_0-d_1\cdots d_{N-1}} & \\ \times P_{1,|\mathcal{D}(\mathcal{S})|=(d_0)} P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1)} \cdots P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1+\cdots d_N)} P_{d_0} \cdots P_{d_N}, & N=N \end{array}\right\} \quad (4.19)$$

where $P_1\{R, SNR||\mathcal{D}(\mathcal{S})| = d_0\} = P_{1,\mathcal{D}(\mathcal{S})|=d_0}$ is given in equation (4.5)

The cooperative diversity after N times type-IV cooperative ARQ scheme is $MN+1$ and the simulation result is shown in Fig.4.11. Obviously, the cooperative diversity is grown up by increasing the size of decoding set after phase by phase and it's efficiency way to increase the cooperative diversity. However, it's also increasing the complexity of the system and the all potential relays need to serve the certain user to transmission. For TP DF type-II and TP DF type-III ARQ schemes, though the system performance is less than the TP DF type-IV, the doesn't active relays can serve another user to help transmission. It's the tradeoff between the system performance and the multi-users communication.

4.2 OP DF ARQ Scheme

Different from two phase ARQ scheme, the one phase ARQ scheme means that cooperative phase obtains source broadcasting phase without relaying phase. we also classify the type from the complexity of relay. The detail discussion is given in follow section.

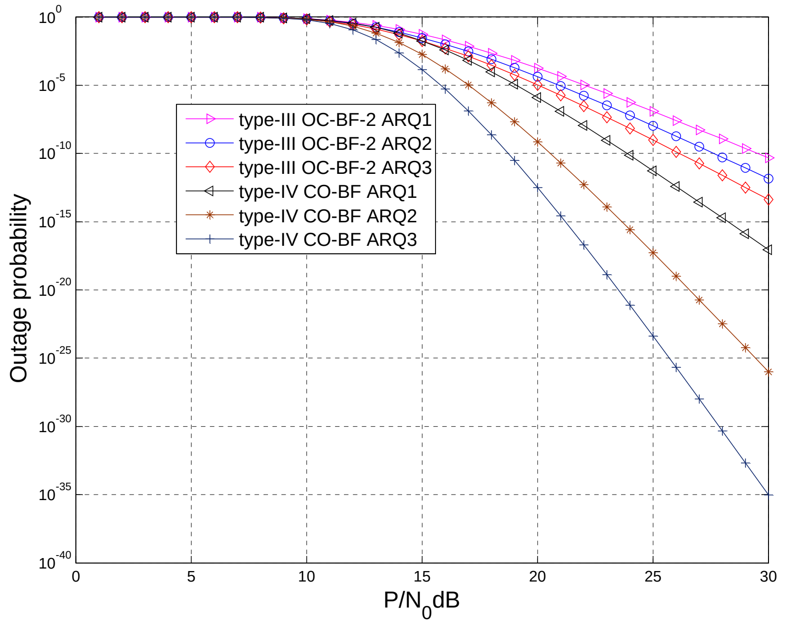

Figure 4.11: Outage probability for TP DF type-III and type-IV in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

4.2.1 OP DF Type-II ARQ Scheme

The relay received signal from source broadcasting in cooperative phase and the successfully decoded relays consist the decoding set. In ARQ1 phase, the decoded correctly relays are chosen from the decoding set. After ARQ1 phase, the following ARQs phase use the same relay as ARQ1 phase. The OP DF ARQ type-II scheme is given in Fig.4.12 The cooperative phase obtains source broadcasting, and the following ARQ phases is the same as TP DF type-II ARQ scheme. The outage probability in source broadcasting is given by

$$P_S = \{(1-\alpha)\gamma|h_{s,d}|^2 < \delta\} = 1 - e^{(-\lambda_0\delta)} \tag{4.20}$$

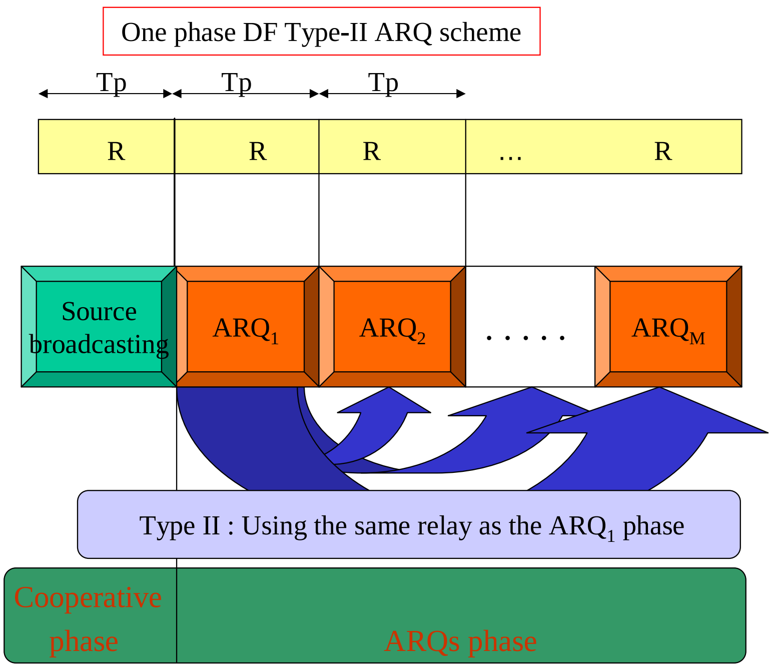

Figure 4.12: OP DF type-II ARQ scheme

Thus, the analysis of OP DF type-II ARQ scheme is similar to TP DF type0II ARQ scheme. The outage probability after N times OP DF type-I scheme is shown as

$$P_{out,N} = \left\{ \begin{array}{cc} P_S & ,N = 0 \\ P_{s_1,|\mathcal{D}(\mathcal{S})|=0} P_{out,N-1} + P_S \sum_{i=1}^{M} A_i^{[1]} P_1^{(N-1)} & ,N \geq 1 \end{array} \right\} \quad (4.21)$$

where $P_{out,0} = P_S$ is given in equation (4.20), and P_1 is also given in equation (4.9) $A_i^{[1]} = \{P_1\{SNR, R||\mathcal{D}(\mathcal{S})|\}P\{|\mathcal{D}(\mathcal{S})| = i\}\}$ is also defined in previous section.

4.2.2 OP DF Type-III ARQ Scheme

The different point between the OP DF type-II and OP DF type-III ARQ schemes are in the ARQ phases. The type-II is using the same relay as previous phase, and type-III re-choose the relay in the decoding set for ARQ1 phase. The detail ARQ scheme is shown in Fig.4.13 We take the P_1 as P_i, then we can obtain the ARQ outage probability. Thus, the overall outage probability for N times one phase type-III ARQ scheme is given

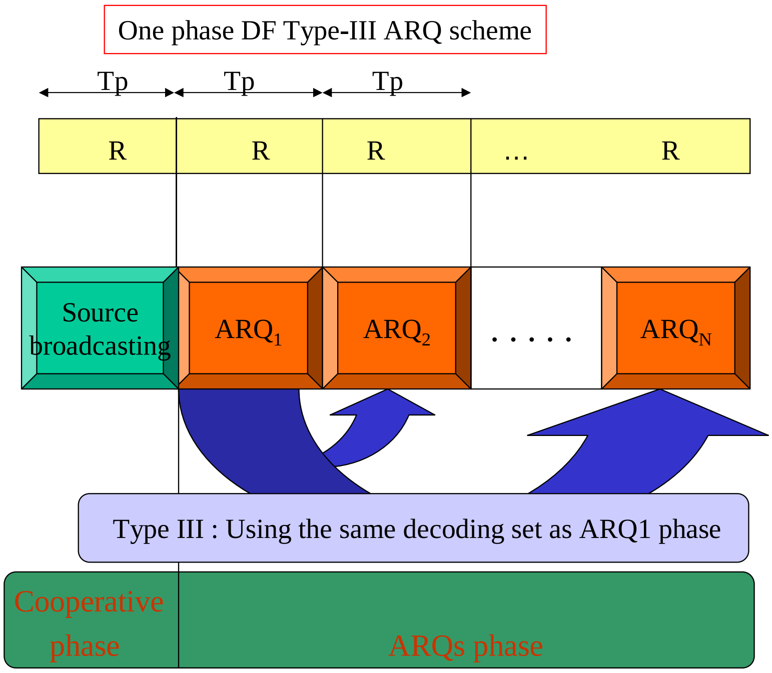

Figure 4.13: OP DF type-III ARQ scheme

as

$$P_{out,N} = \begin{cases} P_S & , N = 0 \\ P_{s_1,|\mathcal{D}(\mathcal{S})|=0} P_{out,N-1} + P_S \sum_{i=1}^{M} A_i^{[1]} P_i^{(N-1)} & , N \geq 1 \end{cases} \tag{4.22}$$

where P_i is given in equation (4.12)

4.2.3 OP DF Type-IV ARQ Scheme

The OP DF type-III is similar as TP DF type-IV scheme except the cooperative phase. The all potential relay always serve certain source, thus the size of decoding set becomes bigger than previous phase. The detail ARQ scheme is shown in Fig4.13.

The analysis for OP DF type-III ARQ scheme is similar to TP DF type-IV ARQ scheme. Thus, the outage probability after N times OP type-III ARQ scheme is given

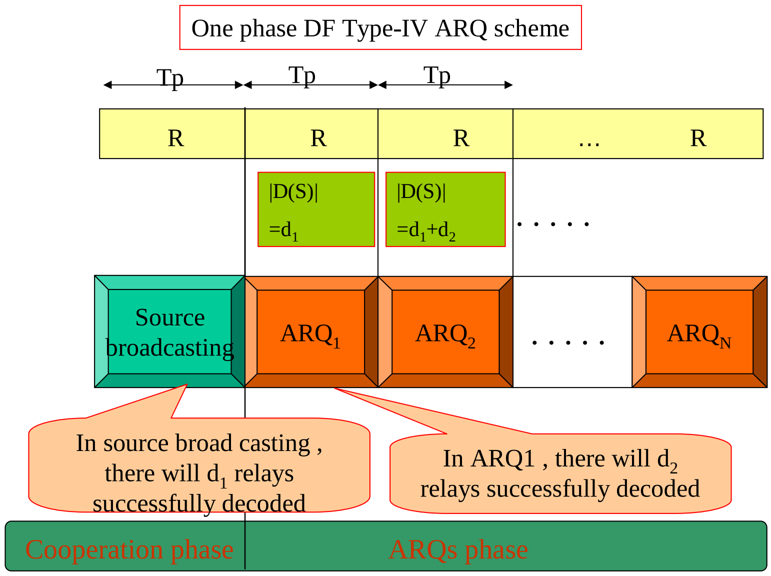

Figure 4.14: OP DF type-IV ARQ scheme

by

$$P_{out,N} = \left\{ \begin{array}{cc} P_S & , N = 0 \\ P_{s_1,|\mathcal{D}(\mathcal{S})|=0} P_{out,N-1} + Y_N & , N \geq 1 \end{array} \right\} \tag{4.23}$$

where $Y_N = P_S \sum_{d_1=1}^{M} \sum_{d_2=0}^{M-d_1} \cdots \sum_{d_N}^{M-d_1-d_2\cdots-d_{N-1}} P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1)} \cdots P_{1,|\mathcal{D}(\mathcal{S})|=(d_0+d_1+\cdots d_N)}$ and $P_{1,|\mathcal{D}(\mathcal{S})|}$ is given in equation (4.5)

4.3 TP AF ARQ Scheme

For AF protocol, it uses all potential relays to help transmission. For cooperative phase, it also includes source broadcasting phase and relaying phase. At receiver, it combines two phase signal by using MRC.

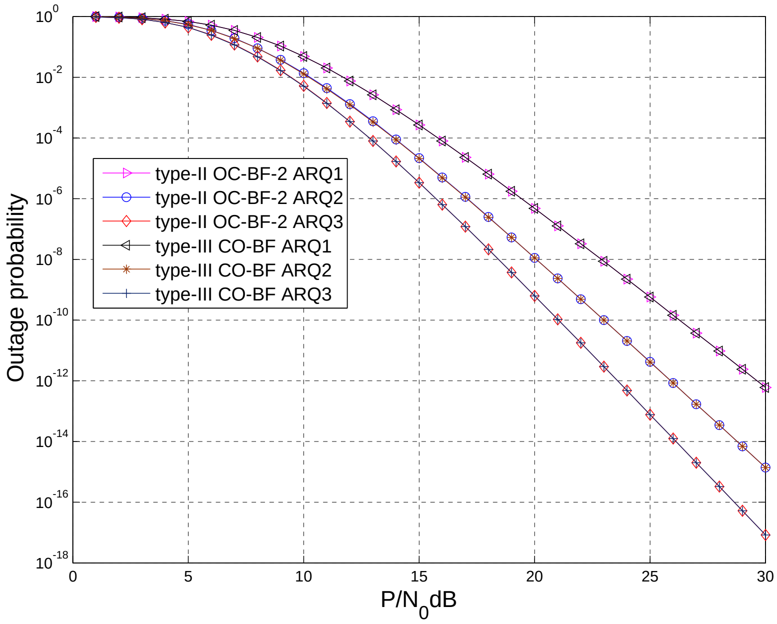

Figure 4.15: Outage probability for OP type-II and type-III DF OC-BF-2 in different ARQ times, $[M = 5, R = 2, \alpha = 0.5]$

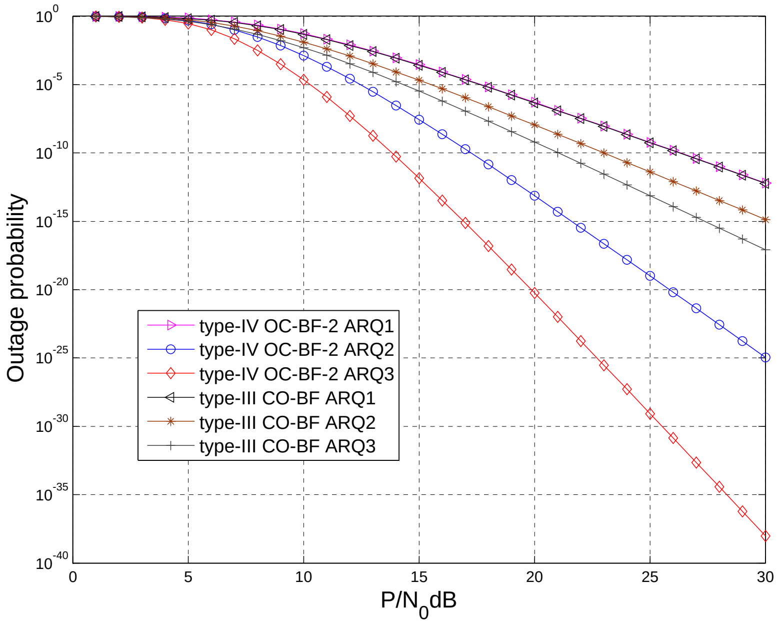

Figure 4.16: Outage probability for OP type-III and type-IV DF OC-BF-2 in different ARQ times, $[M = 5, R = 2, \alpha = 0.5]$

4.3.1 TP AF Type-I ARQ Scheme

Because the relay is memoryless, each ARQ phase including source broadcasting and relaying phase. Thus, except the cooperative phase, the each ARQ phase also takes two times transmission time. Especially, the each ARQ phase also combines two phase signal in destination. The ARQ scheme is shown in Fig.4.17.

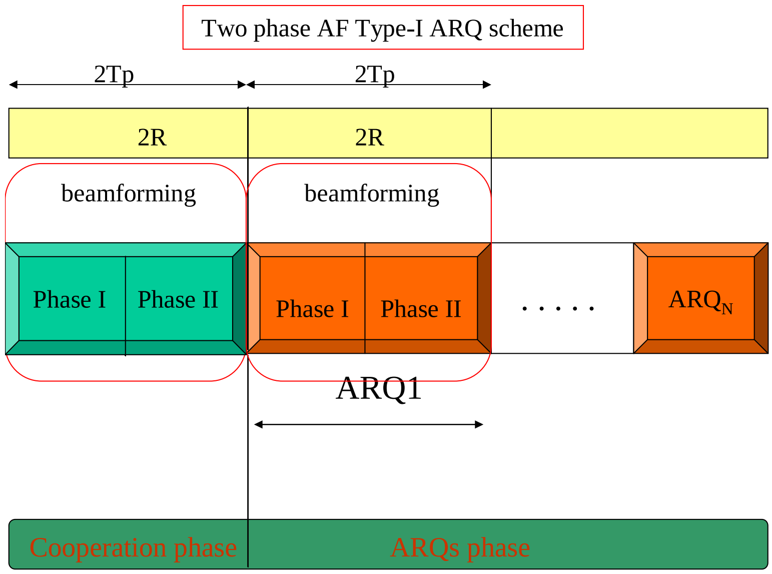

Figure 4.17: TP AF Type-I ARQ scheme.

Because the channel between cooperative phase and ARQ phase are independent. The outage probability after N times ARQ scheme is given by

$$P_{out,N} = P_{out}(SNR, R)^{N+1} \tag{4.24}$$

where $P_{out}(SNR, R)$ is the outage probability with two phase combing for cooperative phase and it has mentioned in previous chapter in equation (3.16).

4.3.2 TP AF Type-II ARQ Scheme

The relay keep the signal in cooperative phase. In each ARQ phase, the relay which choose from cooperative phase still re-transmit signal to destination. The ARQ scheme

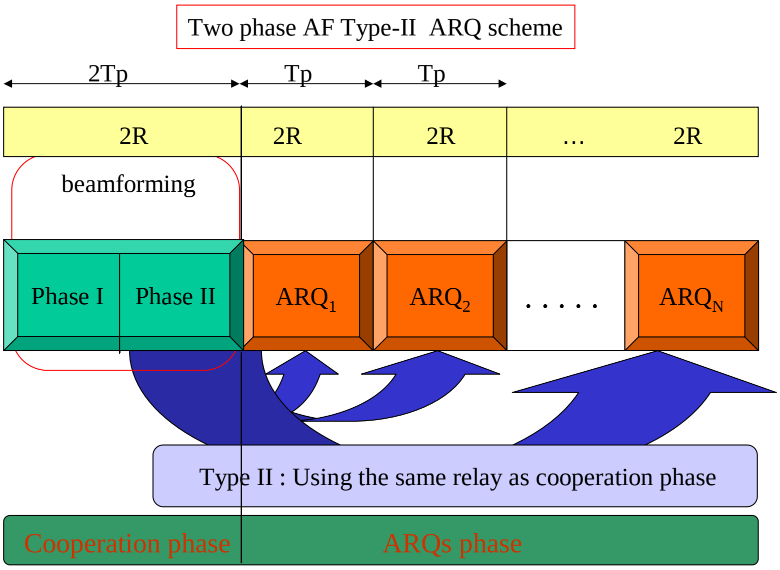

Figure 4.18: TP AF Type-II ARQ scheme.

is shown in Fig.4.18.

Thus, the outage probability after N times ARQ scheme is shown as

$$P_{out,N} = P_{out}(SNR, R)P_{AF,ARQ}^{[1]}(SNR, R)^{(N)} \tag{4.25}$$

where

$$P_{AF,ARQ}(SNR, R)^{[1]} = \left\{ \begin{array}{c} P\{\frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} < \delta\},\{\text{OR case}\} \\ P\{\sum_{i,j} \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} + \frac{\alpha(1-\alpha)\gamma^2\alpha_j\beta_j}{1+(1-\alpha)\gamma\alpha_j+\alpha\gamma\beta_j} < \delta\},\{\text{OC-BF case}\} \\ P\{\sum_{i=1}^{M} \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} < \delta\},\{\text{Co-BF case}\} \end{array} \right\}$$

where $\frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} \sim Exp(\lambda_1 + \lambda_2)$ and $P_{out}(SNR, R)$ is given in equation (3.16).

4.3.3 TP AF Type-III ARQ Scheme

Different from the DF ARQ scheme, the AF ARQ scheme doesn't exist the decoding set problem. The AF ARQ scheme includes cooperative phase and ARQs phases. The cooperative phase is mentioned in previous chapter, and the relays will keep the information that received from the relaying phase in following ARQs phase. We assume that the channel between the cooperative phase and ARQs phase are independent. The ARQ scheme is shown in Fig.4.19. Thus, the total outage probability after N times ARQs is

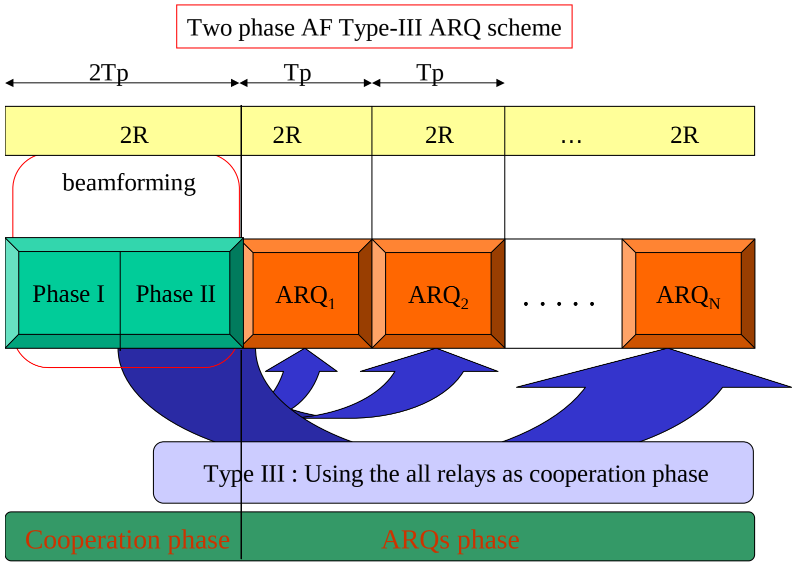

Figure 4.19: TP AF Type-III ARQ scheme.

shown below:

$$P_{out,N} = P_{out}(SNR, R) P^{[2]}_{AF,ARQ}(SNR, R)^{(N)} \tag{4.26}$$

$$P_{AF,ARQ}(SNR, R)^{[2]} = \left\{ \begin{array}{c} P\{\max_{i \in (1,2,\cdots M)} U_i < \delta\}, \{\text{OR case}\} \\ P\{\max_{i,j \in (1,2,\cdots M)} U_i + U_j < \delta\}, \{\text{OC-BF case}\} \\ P\{\max_{i \in (1,2,\cdots M)} U_i < \delta\}, \{\text{Co-BF case}\} \end{array} \right\} \tag{4.27}$$

where$U_i = \frac{\alpha(1-\alpha)\gamma^2\alpha_i\beta_i}{1+(1-\alpha)\gamma\alpha_i+\alpha\gamma\beta_i} \sim Exp(\lambda_1 + \lambda_2)$

From simulation result, we can observe that the cooperative diversity is $MN + 1$ is the same as DF type-IV ARQ scheme. Because all potential relays serve the certain source not only cooperative phase but also ARQs phases. Despite both cases with the same cooperative diversity, the TP AF type-III ARQ scheme still has better SNR offset gain than TP DF type-IV ARQ scheme.

4.4 OP AF ARQ Scheme

The cooperative phase just includes source broadcasting phase without relaying phase and the all relays still received signal form source broadcasting. Thus, the cooperative phase and each ARQ phase take one transmission time to transmit signal to destination.

4.4.1 OP AF Type-II ARQ Scheme

The relay keeps the received signal in cooperative phase. In ARQ1 phase, the relay is chosen from ARQ1 phase by channel quality. In the following ARQs phase, it used the same relays as ARQ1 phase. The ARQ scheme is shown in Fig.4.20.

The outage probability after N times ARQ scheme is given as

$$P_{out,N} = \left\{ \begin{array}{cc} P_S & N=0 \\ P_S P_{AF,ARQ}^{[2]}(SNR,R) & N=1 \\ P_S P_{AF,ARQ}^{[2]}(SNR,R) P_{AF,ARQ}^{[1]}(SNR,R)^{N-1} & N \geq 2 \end{array} \right\} \tag{4.28}$$

where $P_{AF,ARQ}^{[2]}$ is given in equation (4.27)

4.4.2 OP AF Type-III ARQ Scheme

The relay keeps the received signal in cooperative phase. In the following ARQs phase, the relay is re-chosen by channel quality in each ARQ phase. The ARQ scheme is shown in Fig.4.21. The outage probability after N times ARQ scheme is given by

$$P_{out,N} = \left\{ \begin{array}{cc} P_S & ,N=0 \\ P_S P_{AF,ARQ}^{[2]}(SNR,R)^N & ,N \geq 1 \end{array} \right\} \tag{4.29}$$

where $P_{AF,ARQ}^{[2]}$ is given in equation (4.27)

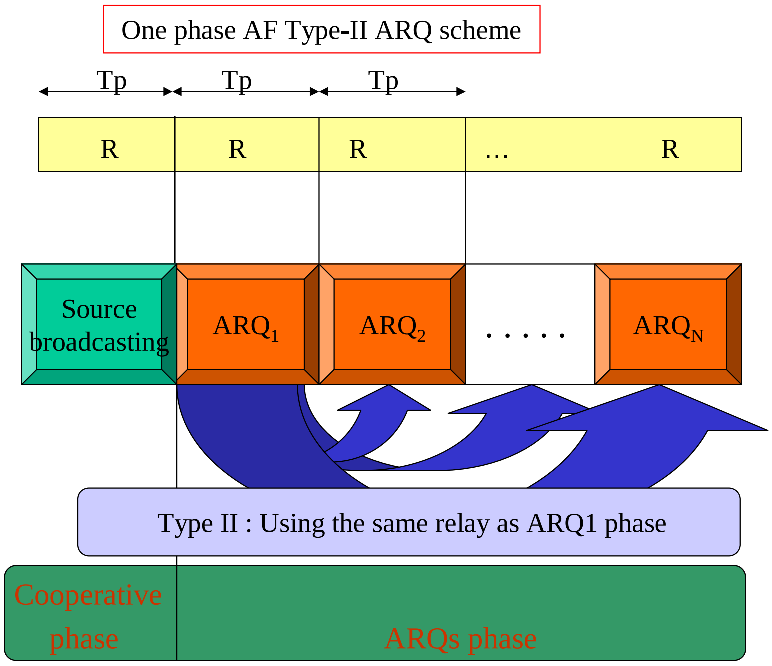

Figure 4.20: OP AF Type-II ARQ scheme.

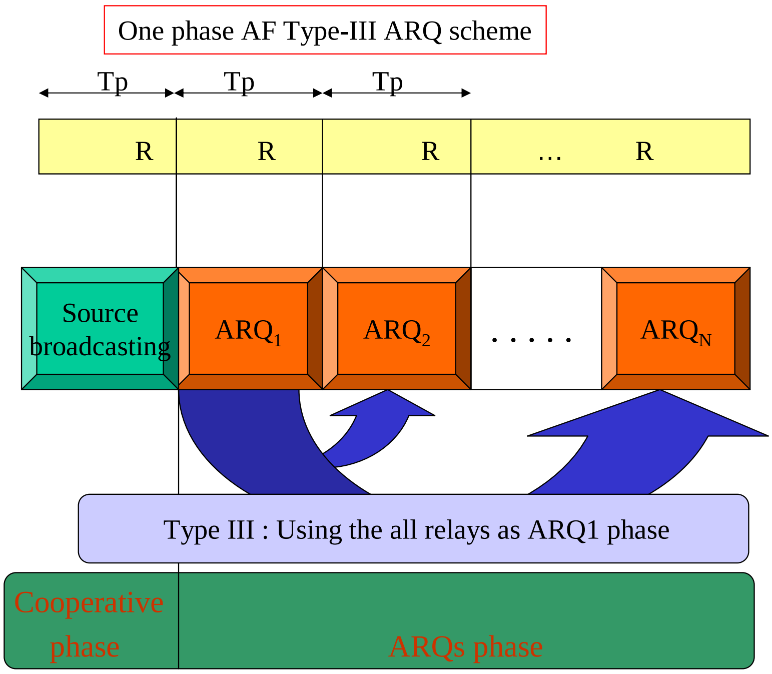

Figure 4.21: OP AF Type-III ARQ scheme.

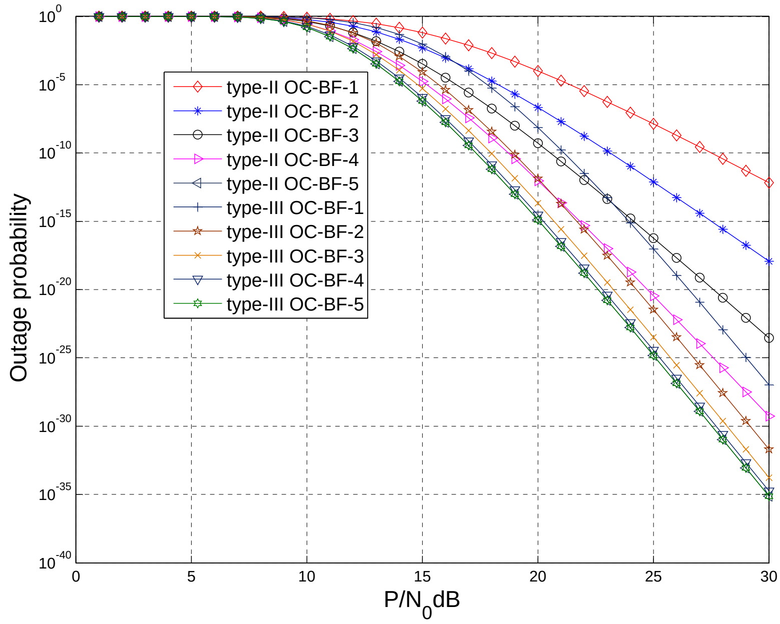

Figure 4.22: Outage probability for TP AF type-II and type-III OC-BF-i $i = 1, 2 \cdots M$, $[M = 5, R = 2, \alpha = 0.5]$

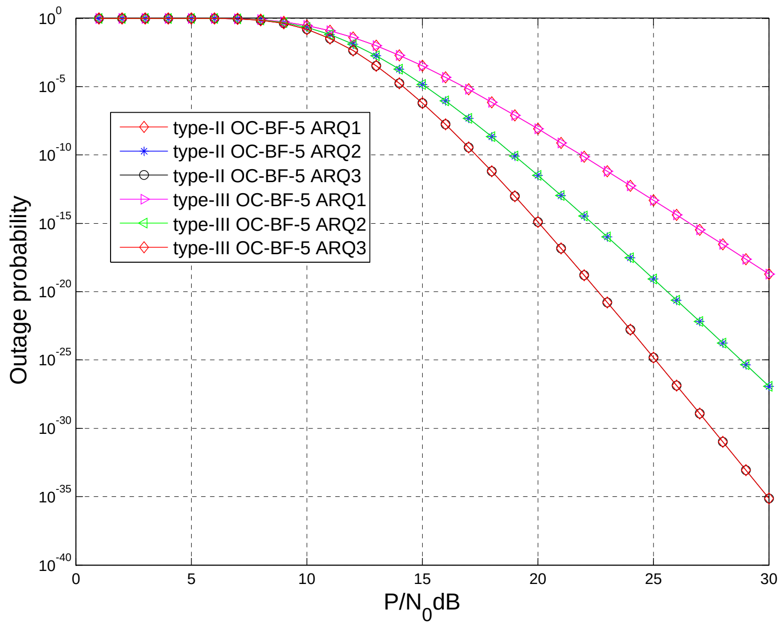

Figure 4.23: Outage probability for TP AF type-II and type-III by using different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

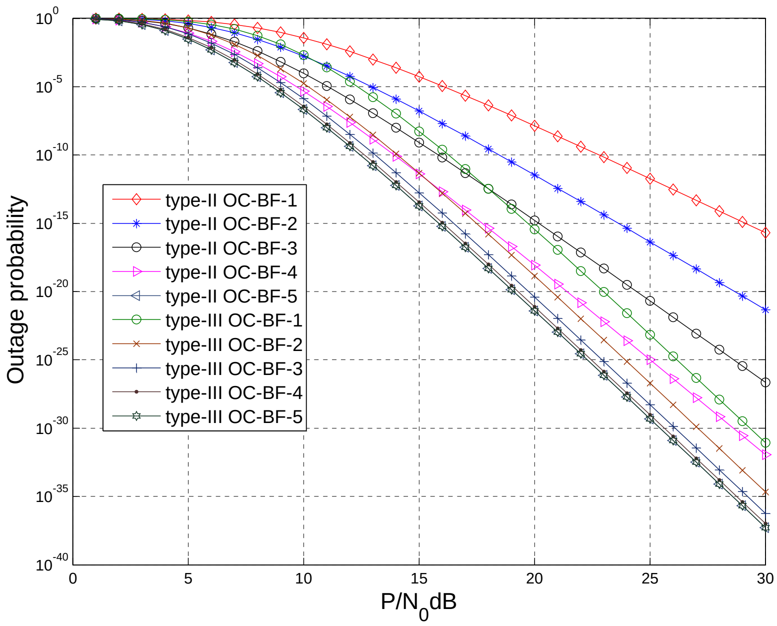

Figure 4.24: Outage probability for OP AF type-II and type-III OC-BF-i, $i = 1, 2 \cdots M$, $[M = 5, R = 2, \alpha = 0.5]$

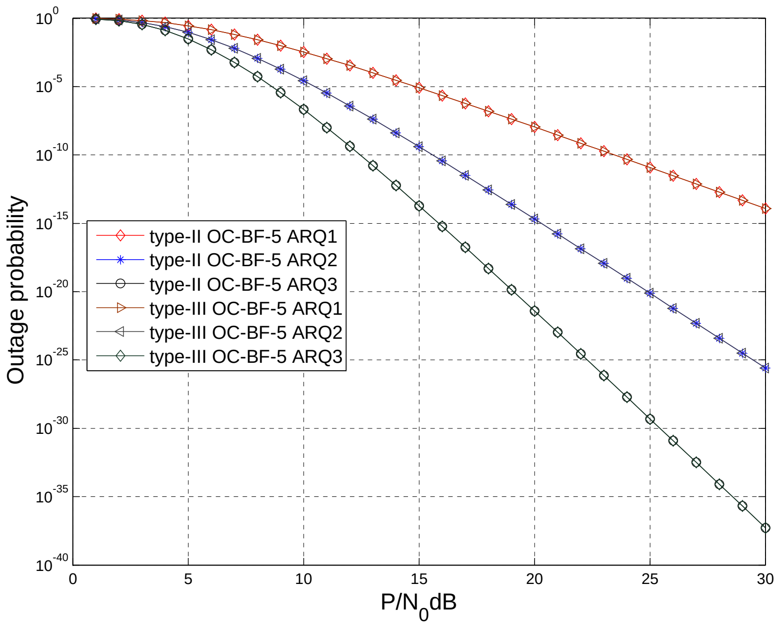

Figure 4.25: Outage probability for OP AF type-II and type-III OC-BF-5 by using different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

Chapter 5

Throughput of Cooperative ARQ: DF vs. AF

In this section, we characterize the effective throughput for the cooperative ARQ schemes presented in the preceding sections. The throughput is defined as the average number of successfully transmitted data divided by the average number of transmission time. By definition, it can be formulated as

$$Throughput = \frac{T_p \times R_{rate} \times [1 - P_{out,N}(R_{rate})]}{T_p \times E\{N\}} = \frac{R_{rate} \times [1 - P_{out,N}(R_{rate})]}{E\{N\}}. \quad (5.1)$$

Two phase:

$$Throughput = \frac{2R \times [1 - P_{out,N}(2R)]}{E\{N\}}. \quad (5.2)$$

One phase:

$$Throughput = \frac{R \times [1 - P_{out,N}(R)]}{E\{N\}}. \quad (5.3)$$

The outage probability $P_{out,N}(R)$ for each cooperative ARQ scheme has been given in the previous chapter. It remains to characterize the expected time of ARQ transmissions, $E\{N\}$, for each scheme. To simplify the following derivation, we define the outage event for cooperative phase as E_0 and the outage event of following ARQs phase as E_i. For the cooperative ARQ , we have

Two phase:

$$\begin{aligned} E\{N\} &= 2P\{\overline{E_0}\} + 3P\{\overline{E_0} \cap E_1\} + 4P\{\overline{E_0} \cap \overline{E_1} \cap E_2\} + \cdots \\ &+ (N+2)P\{\overline{E_0} \cap \overline{E_1} \cap \overline{E_2} \cap \cdots \cap E_N\} \end{aligned} \tag{5.4}$$

One phase:

$$\begin{aligned} E\{N\} &= P\{\overline{E_0}\} + 2P\{\overline{E_0} \cap E_1\} + 3P\{\overline{E_0} \cap \overline{E_1} \cap E_2\} + \cdots \\ &+ (N)P\{\overline{E_0} \cap \overline{E_1} \cap \overline{E_2} \cap \cdots \cap E_N\} \end{aligned} \tag{5.5}$$

DF protocol:

$P_{out,0} = P\{\overline{E_0}\}$, $P_{out,1} = P\{\overline{E_0} \cap \overline{E_1}\} \cdots P_{out,N} = P\{\overline{E_0} \cap \overline{E_1} \cap \overline{E_2} + \cdots + \overline{E_N}\}$ Because $P\{\overline{E_0} \cap E_1\} + P\{\overline{E_0} \cap \overline{E_1}\} = P\{\overline{E_0}\}$, we can obtain the $P\{\overline{E_0} \cap E_1\} = P_{out,0} - P_{out,1}$. By using the similar method to analyze the average transmission, we can get

[Two phase]

$$\begin{aligned} E\{N\} &= 2(1 - P_{out,0}) + 3(P_{out,0} - P_{out,1}) + \cdots + \\ & (N+1)(P_{out,N-2} - P_{out,N-1}) + (N+2)P_{out,N-1} \\ &= 2 + \sum_{i=0}^{N-1} P_{out,i}. \end{aligned} \tag{5.6}$$

[One phase]

$$
\begin{aligned}
E\{N\} &= (1-P_{out,0}) + 2(P_{out,0}-P_{out,1}) + \cdots + \\
&\quad (N-1)(P_{out,N-2}-P_{out,N-1}) + (N)P_{out,N-1} \\
&= 1 + \sum_{i=0}^{N-1} P_{out,i}. \qquad (5.7)
\end{aligned}
$$

AF protocol:

Because AF protocol without decoding set problem, the outage event in each ARQ phase is independent event. $P_{out,0} = P\{\overline{E_0}\}$, $P_{out,1} = P\{\overline{E_0} \cap \overline{E_1}\} = P\{\overline{E_0}\}P\{\overline{E_1}\}$ $\cdots$ $P_{out,N} = P\{\overline{E_0} \cap \overline{E_1} \cap \overline{E_2} \cap \cdots \cap \overline{E_N}\} = P\{\overline{E_0}\}P\{\overline{E_1}\} \cdots P\{\overline{E_N}\}$. we can obtain the $P\{\overline{E_0} \cap E_1\} = P\{\overline{E_0}\}P\{E_1\} = P_{out,0} - P_{out,1}$. Thus, the average transmission of cooperative ARQ for AF protocol can be shown as

[Two phase]

$$
\begin{aligned}
E\{N\} &= 2(1-P_{out,0}) + 3(P_{out,0}-P_{out,1}) + \cdots + \\
&\quad (N+1)(P_{out,N-2}-P_{out,N-1}) + (N+2)P_{out,N-1} \\
&= 2 + \sum_{i=0}^{N-1} P_{out,i}. \qquad (5.8)
\end{aligned}
$$

[One phase]

$$
\begin{aligned}
E\{N\} &= (1-P_{out,0}) + 2(P_{out,0}-P_{out,1}) + \cdots + \\
&\quad (N-1)(P_{out,N-2}-P_{out,N-1}) + (N)P_{out,N-1} \\
&= 1 + \sum_{i=0}^{N-1} P_{out,i}. \qquad (5.9)
\end{aligned}
$$

From the simulation result, he effective way to improve the throughput is using type-IV ARQ scheme for DF OC-BF. For AF OC-BF, the throughput can be more effectively improved by using more best relays.

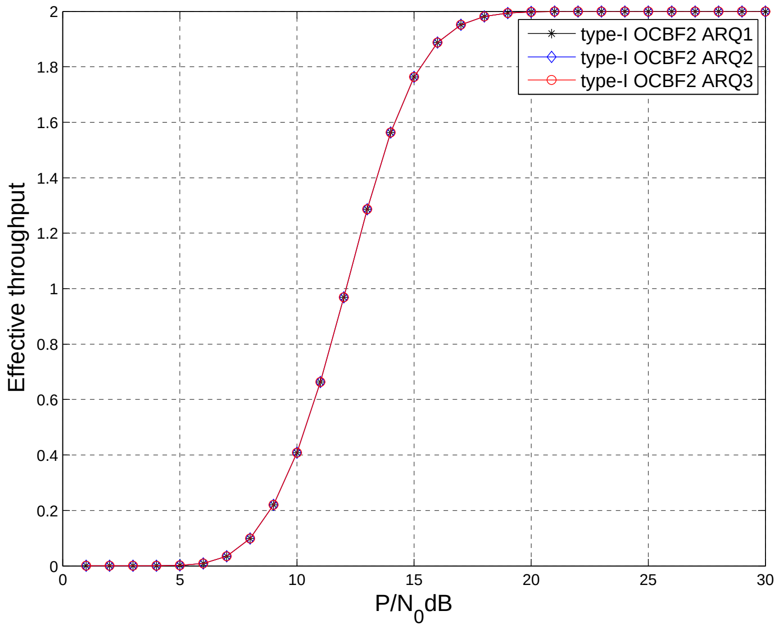

Figure 5.1: Effective throughput for TP DF type-I in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

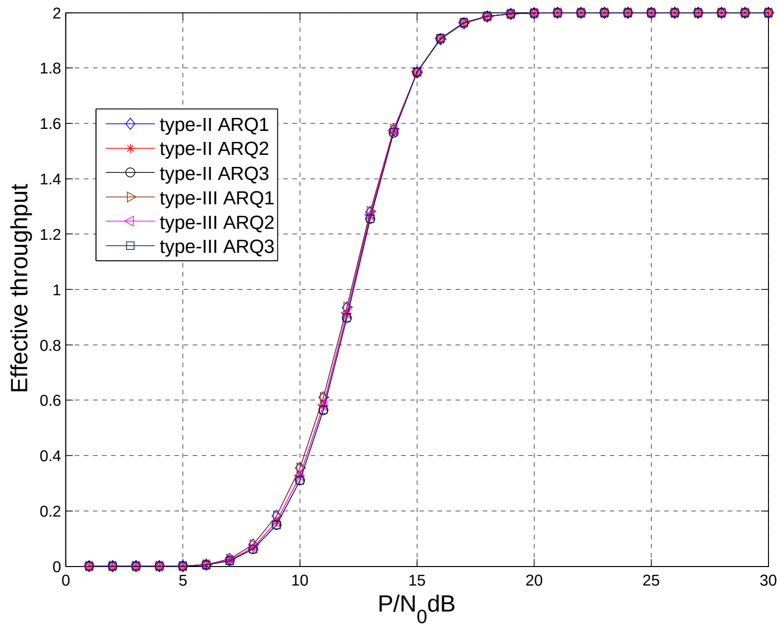

Figure 5.2: Effective throughput for TP DF type-II and type-III in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

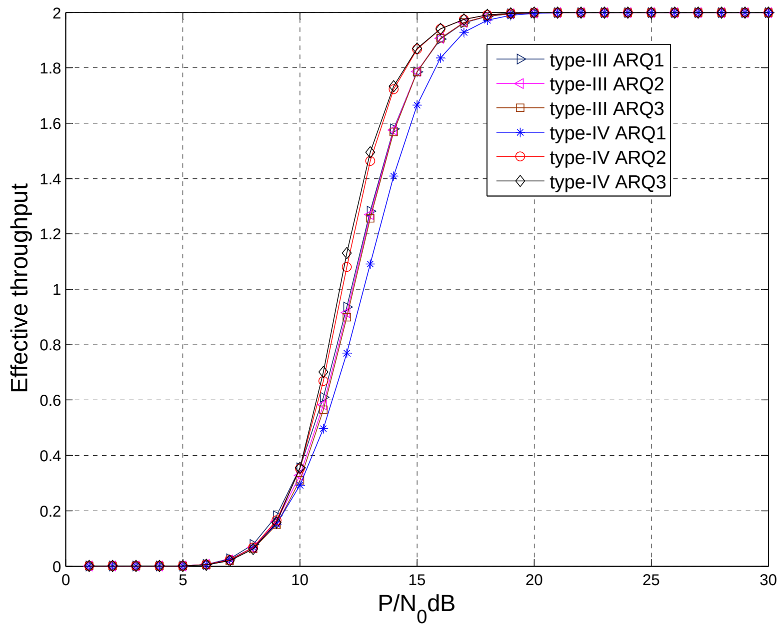

Figure 5.3: Effective throughput for TP DF type-III and type-IV in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

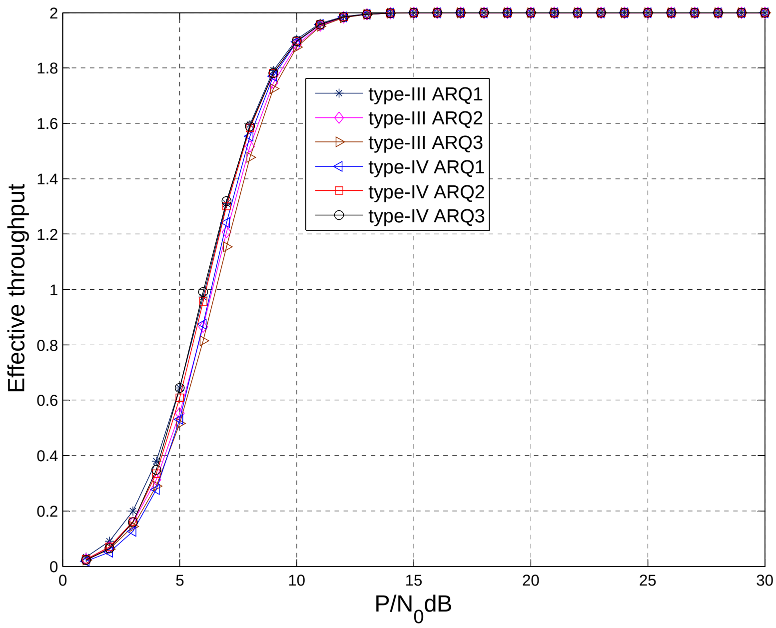

Figure 5.4: Effective throughput for OP DF type-III and type-IV in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

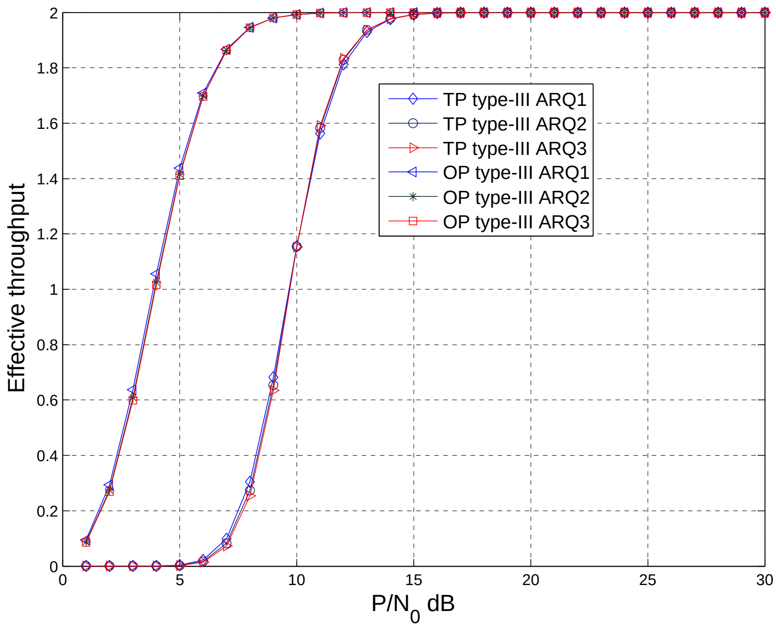

Figure 5.5: Effective throughput for TP AF type-III and OP AF type-III in different ARQ times $[M = 5, R = 2, \alpha = 0.5]$

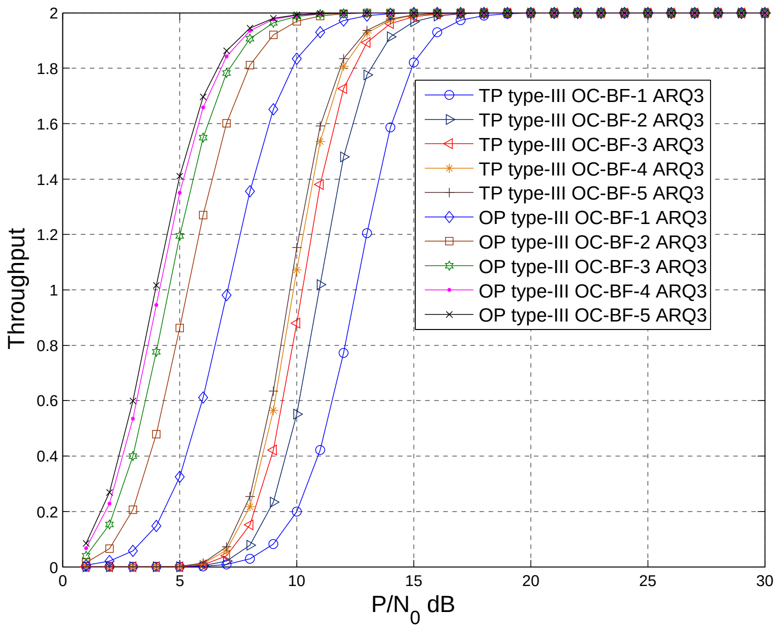

Figure 5.6: Effective throughput for TP AF type-III and OP AF type-III OC-BF-i $i = 1, 2, \cdots M$ $[M = 5, R = 2, \alpha = 0.5]$

Chapter 6

Conclusions

We investigated the outage probabilities and characterized the effective throughput of several types cooperative ARQ scheme for DF and AF protocols by using opportunistic cooperative beamforming. For DF OC-BF, the outage probability of OC-BF-M can be achieved by OC-BF-2 and the outage performance is constrained by decoding set. For AF OC-BF, the outage probability becomes better by choosing more relays and the SNR offset can be reduced by using one more relay. In the effective throughput, the effective way to improve the throughput is using type-IV ARQ scheme for DF OC-BF. For AF OC-BF, the throughput can be more effectively improved by using more best relays.

Appendix A

$$\int_0^{\frac{T}{n}}\int_0^{\frac{T-(n)t_n}{n-1}}\int_0^{\frac{T-(n)t_n-(n-1)t_{n-1}}{n-2}}\cdots\int_0^{\frac{T-(n)t_n-(n-1)t_{n-1}\cdots(2)t_2}{1}} t_n^{L-n}dt_1dt_2\cdots dt_n = F_N(T,L)$$

$$= \frac{T^L(L-n)!}{n!n^{L-n}L!} \tag{A.1}$$

proof:

n=2 : the above equation can be given as

$$\int_0^{\frac{T}{2}}\int_0^{T-2t_2} t_2^{L-2}dt_1dt_2 = \int_0^{\frac{T}{2}}(T-2t_{2)}t_2^{L-2}dt_2 = F_2(T,L) \tag{A.2}$$

By using the formula that is given by

$$\int_0^u x^{v-1}(u-x)^{p-1}dx = u^{(p+v-1)}\frac{(p-1)!(v-1)!}{(p+v-1)!} \tag{A.3}$$

We can obtain the function: $F_2(T,L) = \frac{T^L(L-2)!}{2!2^{(L-2)}L!}$

n=3: assume $s = t - 3t_3$

$$\int_0^{\frac{T}{3}} \int_0^{\frac{T-3t_3}{2}} \int_0^{T-3t_3-2t_2} t_3^{L-3} dt_1 dt_2 dt_3 = \int_0^{\frac{T}{3}} \int_0^{\frac{T-3t_3-2t_2}{2}} (s-2t_2) t_3^{L-3} dt_2 dt_3$$
$$= \int_0^{\frac{T}{3}} \int_0^{\frac{s}{2}} (s-2t_2) t_3^{L-3} dt_2 dt_3 = \int_0^{\frac{T}{3}} F_2(s,2) t_3^{L-3} dt_3 = F_3(T,L)$$
$$= \frac{T^L (L-3)!}{3! 3^{(L-3)} L!} \tag{A.4}$$

n=4: assume $s_1 = T - 4t_4 - 3t_3$,$s_2 = T - 4t_4$

$$\int_0^{\frac{T}{4}} \int_0^{\frac{T-4t_4}{3}} \int_0^{\frac{T-4t_4-3t_3}{2}} \int_0^{T-4t_4-3t_3-2t_2} t_4^{L-4} dt_1 dt_2 dt_3 dt_4$$
$$= \int_0^{\frac{T}{4}} \int_0^{\frac{T-4t_4}{3}} \int_0^{\frac{s_1}{2}} \int_0^{s_1-2t_2} t_4^{L-4} dt_1 dt_2 dt_3 dt_4$$
$$= \int_0^{\frac{T}{4}} \int_0^{\frac{T-4t_4}{3}} F_2(s_1,2) t_4^{L-4} dt_3 dt_4 = \int_0^{\frac{T}{4}} F_3(s_2,3) t_4^{L-4} dt_4 = F_4(T,L) \tag{A.5}$$

we assume n=k, $F_k(T,L) = \underbrace{\int_0^{T/k} \cdots \int_0^{T-(k)t_k-(k-1)t_{k-1}\cdots 2t_2} t_k^{L-k} dt_1 \cdots dt_k} = \frac{T^L(L-k)!}{k! k^{(L-k)} L!}$

Thus,when n=k+1, $s_{k+1} = T - (k+1)t_{k+1}$, the $F_{k+1}(T,L)$ is given as

$$\int_0^{T/(k+1)} \cdots \int_0^{T-(k+1)t_{k+1}-(k)t_k\cdots 2t_2} t_{k+1}^{L-(k+1)} dt_1 \cdots dt_{k+1}$$
$$= \int_0^{\frac{T}{k+1}} F_k(s_{k+1}, k-1) t_{k+1}^{L-(k+1)} dt_{k+1} = \int_0^{\frac{T}{k+1}} \frac{T^L (L-k)!}{k! k^{(L-k)} L!} t_{k+1}^{L-(k+1)} dt_{k+1}$$
$$= \frac{T^L (L-(k+1))!}{(k+1)!(k+1)^{(L-(k+1))} L!} = F_{k+1}(T,L) \tag{A.6}$$

Bibliography

[1] E. Telatar, "Capacity of multi-antenna gaussian channels," *European Trans. on Telecommunications*, vol. 10, no. 6, pp. 585–595, 1999.

[2] J. N. Laneman and G. W. Wornell, "Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks," *IEEE Trans. on Information Theory*, vol. 59, no. 10, pp. 2415–2525, 2003.

[3] David N.C.Tse J.Nicholas Laneman, "Coopeative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Trans. on Information Theory*, vol. 50, pp. 3062–3080, 2004.

[4] Y. Zhao, R. Adve, and T. J. Lim, "Improving amplify-and-forward relay networks: optimal power allocation versus selection," in *Proc. IEEE ISIT*. Seattle, WA, July 2006.

[5] Aggelos Bletssa Hyundong Shin and Moe Z., "Cooperative communicaions with outage-optimal opportunistic relaying," *IEEE Trans. on Wireless Communications*, vol. 6, no. 9, pp. 3450–3460, 2007.

[6] Jung-Bin Kim and Dongwoo Kim., "Coopeative system with distributed beamforming and its outage probability," pp. 1638–1641, 2007.

[7] Y. Zhao, R. Adve, and T. J. Lim, "Beamforming with limited feedback in amplify-and-forward cooperative networks," in *Proc. IEEE Globecom*. Washington, D.C., Nov. 2007.

[8] T. W. Ban, B. C. Jung, D. K. Sung, and W. Choi, "Performance analysis of two relay selection schemes for cooperative diversity," in *Proc. IEEE PIMRC*. Athens, Greece, Sep. 2007.

[9] I. Stanojev, O. Simeone, and Y. Bar-Ness, "Performance of multi-relay collaborative hybrid-ARQ protocols over fading channels," *IEEE Communications Letters*, vol. 10, no. 7, pp. 522–524, 2006.

[10] J.-B. Kim and D. Kim, "Cooperative system with distributed beamforming and its outage probability," in *Proc. IEEE VTC-Spring*. Dublin, Ireland, April 2007.

[11] M.O. Hasna and M.S. Alouini, "End-to-end performance of tranmission systems with relays over rayleigh-fading channels," *IEEE Trans. on Communications*, vol. 2, no. 6, pp. 1126–1131, 2003.

[12] Karim G. Seddik Ahmed K. Sadek K.J. Ray Liu, "Outage analysis and optimum power allocation for multinode relay networks," *Signal Processing Letters*, vol. 14, no. 6, pp. 1126–1131, 2007.

[13] I.S. Gradshteyn and I.M. Ryzhik, *Table of Integrals, Series, and Products*, Elsevier, 7rd edition, 2007.

[14] SAEED GHAHRAMANI, *Fundamentals of probability with stochastic processes*, Prentice Hall, 3rd edition, 2005.

[15] H.N. Nagarja H.A.David, *Order statistics*, Wiley, 3rd edition, 2003.