JOURNAL OF SOCIAL SCIENCES AND TECHNICAL EDUCATION
Jurnal Sains Sosial dan Pendidikan Teknikal 1(1) (2020), 89-97

Maximal Ratio Combiner in Time-Varying Channel Amplify-and-Forward Cooperative Communication Network

(Penggabung Nisbah Maksima dalam Saluran Variasi Masa Rangkaian Komunikasi Kerjasama Amplify-and-Forward)

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Abstract

This manuscript focuses on the Multiple Symbol Double Differential (MSDD) detection scheme in Amplify-and-Forward (AF) cooperative communication network employing Maximal Ratio Combining (MRC) at the receiver. In the wireless communication environment, high mobility, limited bandwidth as well as transmission capacity, and unreliable fading channels affects the channel transmission. Most of the previous works consider a flat-fading scenario, but this assumption is unjustified as cooperative communications are specially utilized in the mobile system, wherein the end users are mobile. As the end user moves under high-velocity environment, the channels experience fast fading which result in performance degradation. Thus, an AF-based cooperative communication method is proposed so as to mitigate the challenges. A comprehensive error probability and outage probability performance analysis are carried through the flat fading Rayleigh environment for the proposed MRC. Specifically, Pairwise Error Probability (PEP) expressions for the proposed MRC detectors are derived based on the Moment Generating Function (MGF). On top of that, Probability Density Function (PDF) analysis expression is derived to obtain the outage probability of the network. It can be observed that the MRC new combining weights that are based on the channel second-order statistic, perform better in terms of error probability as compare to the conventional MRC under time-varying channel environment. Furthermore, the simulations of the proposed MRC and the derived numerical analysis also validated under different faded channel and different number of relays.

Keywords: Cooperative communication network, Amplify-and-forward (AF), Maximal Ratio Combining (MRC)

Received: July 11, 2020; **Accepted**: September 11, 2020; **Published**: October 20, 2020
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INTRODUCTION

In the last decade, cooperative communication or diversity in wireless mobile communication network has developed exceptionally and the demand for the technologies will greatly grow in the forthcoming years. In order to cater the increasing demand, many researches had been made to decrease the Bit Error Rate (BER) and the network outage probability error performance. This is to achieve high transmission bandwidth and to establish more reliable communication. In the existing works, it is assumed that the channels stay fixed during the two symbol transmission intervals so as to eliminate the channel knowledge at the receiver. Differential detection has attracted much attention because of its capability to omit channel knowledge estimation at the destination. The modulation scheme depending on the consecutive phase responses of the channel which in turn, does not need accurate phase reference of the signal received.

The associated works based on differential transmission methods are analyzed in (Himsoon, Su, & Liu, 2005; Tarokh & Jafarkhani, 2000; Zhao & Li, 2005; Annavajjala, Coman & Milstein, 2005; El-Hajjar & Hanza, 2010; Kanthimathi, Amutha, & Bhavatharak, 2019). A two-user cooperation systems employing differential method for AF cooperative communication has been considered in (Himsoon et al., 2005; Zhao & Li, 2005; Annavajjala et al., 2005). The signals from the directly transmitted channel and the relayed channel are combined in regards to the MRC method, which needs the statistical knowledge for all transmission channels. A simple error rate performance, BER is derived based on the Moment Generating Function (MGF) method (Himsoon et al., 2005). The expression is derived to optimize the power allocation among terminals for system performance improvement. Despite the fact the formulation is simple, it requires exhaustive numerical search in order to achieve the optimization. Thus, Zhao et al. in (Zhao & Li, 2005) derived the Signal-to-Noise Ratio (SNR), PDF as well as average BER in closed-form expression for the proposed method. But the method requires the overall transmission links average gains.

In the practical scenario particularly in the time-varying channel, the frequency offsets also cause the transmission block to act as a time-varying channel, which degrades the performance of the network. Most existing literatures consider developing cooperative diversity system that bypass the channel knowledge without assuming the frequency offsets effect over the wireless channels.

In order to eliminate the tedious task of obtaining channel estimation and frequency offsets knowledge, Double Differential (DD) modulation and Multiple Symbol Detection (MSD) scheme in AF cooperative diversity system are developed in (Ling, Zen, Othman, & Hamid, 2017). From (Ling et al., 2017), the scheme utilized a direct gain method at the receiver. It is observed that the scheme can be further improved and developed by applying the diversity combiner MRC at the desired destination. The diversity combiners state-of-art can be referred in (Brennan, 2003). The mutual aim of the diversity combining methods is to obtain the weighting factor, ω for the multiple receiving signals from different paths to reduce the channel fading effect. Hence, the objectives of this research are to develop an improved MRC that bypasses the channel and frequency offsets knowledge. Secondly, the error and outage probability numerical analysis are derived to verify the simulation.

The organization of the manuscript is presented as follows. In Methodology section, the proposed combining method is introduced briefly. The Methodology subsections explain the proposed MRC method and followed by the derivation of the numerical analysis. Next in Results and Discussion section, the simulation and numerical analysis results as well as its discussion are presented. Finally, Conclusion section outlines the significant outcomes concluded during the investigation.

METHODOLOGY

A wireless AF cooperative relaying system utilizing MRC at the destination is illustrated in Figure 1, where h_1 represents the relayed channel while h_2 indicates the direct channel from the source to the destination. Without the channel and frequency offsets knowledge estimation, a group of static gain based on the transmission channels second-order statistics is studied.

In MRC, the receiving independent signal is first co-phased and weighted proportionately to their channel gain. By obtaining the complex conjugate of the channel gain, each path weighting factor can be determined. Then, the weighted signals combined. Figure 1 depicts the general block diagram of the 2-branch MRC. The gains, w_a and w_b are directly proportional to the phase estimation. Due to the challenges, the instantaneous combining weights are considered in the MRC performance analysis for validation.

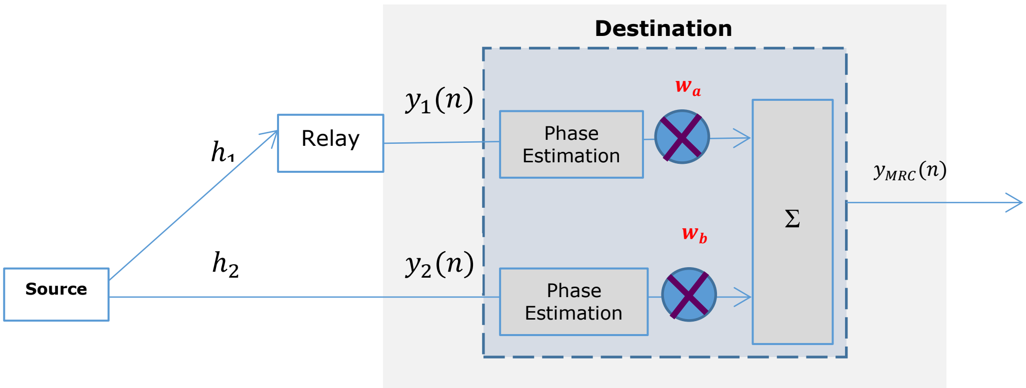


Figure 1. Block diagram of MRC scheme for cooperative communication network.

<u>MAXIMAL RATIO COMBINER</u>

Based on Autoregression (AR(2)), the direct and relayed channels can be expressed as:

$$\begin{gathered} y_{s,d}[l] = P_S[\alpha_{s,d}^2 y_{s,d}[l-1]y_{s,d}[l-2] + \alpha_{s,d}x[l]y_{s,d}[l-1]]e^{j2\pi f_{s,d}[l]} + n_{s,d}[l] \\ n_{s,d}[l] = w_{s,d}[l] - \alpha_{s,d}^2 y[l-1]w_{s,d}[l-1] - \alpha_{s,d}x[l]w_{s,d}[l-2] + 2\sqrt{1-\alpha_{s,d}^2}\sqrt{P_S}z[l]\varepsilon_{s,d}[l] \end{gathered} \tag{2.1}$$

and

$$y_{s,r_id}[l] = G[\alpha_{s,r_id}^2 y[l-1]y_{s,r_id}[l-2] + \alpha_{s,r_id}x[l]y_{s,r_id}[l-1]]e^{j2\pi f_{s,r_i,d}} + n_{s,r_id}[l] \tag{2.2}$$

where

$$\begin{gathered} n_{s,r_i,d}[l] = w_{s,r_id}[l] - \alpha_{s,r_id}^2 y[l-1]w_{s,r_i,d}[l-1] - \alpha_i x[l]w_{s,r_i,d}[l-2] \\ + 2G\sqrt{1-\alpha_i^2}\sqrt{P_S}z[l]h_{r_id}[l]\varepsilon_{s,r_i}[l] \end{gathered} \tag{2.3}$$

P_S denotes the power source, G is the relay gain, α represents the channel fading rates and $j2\pi f$ is the perturbed frequency offsets. It is assumed that the noise $n_{s,d}[l]$ and $n_i[l]$ are complex Gaussian random variables. It applies similarly to their average noise variances and are written as:

$$\sigma^2_{n_{s,d}} = 1 + \alpha^4_{s,d} + \alpha^2_{s,d} + 2P_S(1 - \alpha^2_{s,d}) \tag{2.4}$$

$$\sigma^2_{n_{s,r_i,d}} = \sigma^2_{s,r_i,d}\left(1 + \alpha^4_{s,r_i,d} + \alpha^2_{s,r_i,d} + 2\rho_{s,r_i,d}\left(1 - \alpha^2_{s,r_i,d}\right)\right) \tag{2.5}$$

The combined signals received at the destination based on MRC in (Brennan, 2003) is expressed as:

$$\begin{aligned} \varsigma = \beta_0(y_{s,d}[n]y^*_{s,d}[n-1])(y_{s,d}[n-1]y^*_{s,d}[n-2])^* \\ +\beta_1(y_{s,r_i,d}[n]y^*_{s,r_i,d}[n-1])(y_{s,r_i,d}[n-1]y^*_{s,r_i,d}[n-2])^* \end{aligned} \tag{2.6}$$

where

$$\beta_0 = \frac{\alpha_{s,d}}{\sigma^2_{n_{s,d}}} \tag{2.7}$$

$$\beta_1 = \frac{\alpha_{r,d}}{\sigma^2_{n_{r,d}}} \tag{2.8}$$

$\alpha_{s,d}$ and $\alpha_{r,d}$ are the channel fading factors. Under slow fading scenario, as the fading factor value is 1. From (2.3), it is observed that the noise variance is related with the coefficient of the channel, $h_{r,d}[l]$. It is assumed that the channel coefficient is unknown. Therefore, the mean of the noise variance is applied as the combining weight for the conventional DD transmission method. The slow fading channels' weigh is expressed as:

$$\beta_{0(slow)} = \frac{1}{3} \tag{2.9}$$

$$\beta_{1(slow)} = \frac{1}{3(1 + G_i^2)}, \qquad i = 1, \dots, R \tag{2.10}$$

Under fast fading channels, the mean of the noise variances is written as:

$$E\{\sigma^2_{n_{s,d}}\} = 1 + \alpha^4_{s,d} + \alpha^2_{s,d} + 2\left(1 - \alpha^2_{s,d}\right)Ps \tag{2.11}$$

and

$$E\left\{\sigma^2_{n_{s,r_i,d}}\right\} = (1 + G_i^2)(1 + \alpha^4_{s,r_i,d} + \alpha^2_{s,r_i,d}) + 2\left(1 - \alpha^2_{s,r_i,d}\right)G_i^2 P_S) \tag{2.12}$$

Thus, the proposed and modified weight factors for the time-varying channels can be expressed as:

$$\beta_{0(fast)} = \frac{\alpha_{s,d}}{1 + \alpha^4_{s,d} + \alpha^2_{s,d} + 2\left(1 - \alpha^2_{s,d}\right)Ps} \tag{2.13}$$

and

$$\beta_{1(fast)} = \frac{\alpha_{s,r_i,d}}{(1 + G_i^2)(1 + \alpha^4_{s,r_i,d} + \alpha^2_{s,r_i,d}) + 2\left(1 - \alpha^2_{s,r_i,d}\right)G_i^2 P_S)} \tag{2.14}$$

From (2.13) and (2.14), it can be noted that the proposed weight factor is dependent on the α, G and the Ps. Since the proposed weight is related with the channel fade rate, each received signals experiences a dynamic weight to the received signals. As the channel varies rapidly, the received signals' performance decreases. Hence, during the detection process, only a small amount of signal amplitude is considered. In other words, the channels with strong signals are further amplified.

PERFORMANCE ANALYSIS OF MAXIMAL RATIO COMBINER

In this subsection, numerical analysis in terms of error and outage probability are derived accordingly. MGF and PFD based are employed for error and outage probability analysis, respectively.

Error Probability Performance Analysis

This section evaluates the MSDD AF network utilizing MRC under different channel mobility. It is assumed that x_1 is sent, and x_2 is decoded erroneously at the decoder. Referring to Zhang (2015), an erroneous event happens when:

$$||\varsigma - x_1||^2 > ||\varsigma - x_2||^2 \tag{2.15}$$

which can be simplified as:

$$\big||n|\big| > ||a|| \tag{2.16}$$

where n represents the noise terms, a denotes the received signal and $x_1 - x_2 = d_{min}$ By replacing ς from (2.7) into (2.16) as well as utilizing the optimal combining weight β_0 and β_1, the erroneous event can be further expressed as:

$$\xi \triangleq |d_{min}|^2(\alpha_{s,d}\beta_0|y_{s,d}[l-1]|^2|y_{s,d}[l-2]|^2 + \alpha_{s,r_i,d}\sum_{i=1}^{R}\beta_{1i}|y^*_{s,r_i,d}[l-1]|^2\,|y^*_{s,r_i,d}[l-2]|^2) + d^*_{min}(\beta_0 y^*_{s,d}[l-1]y^*_{s,d}[l-2]n_{s,d}[l] + \sum_{i=1}^{R}\beta_{1i}y^*_{s,r_i,d}[l-1]\,y^*_{s,r_i,d}[l-2]n_{s,r_i,d}[l] < 0 \tag{2.17}$$

It can be observed that the last 2 terms of the decision parameter ξ that is conditioned on $y_{s,d}$, $y_{s,r_i,d}$ and h_{r_id}, constitutes of Gaussian noise. Also, it is noted that the 2 noise terms are mutually uncorrelated and independent with each other as they are complex conjugate. Thus, the mean and the variance of the Gaussian noise component are expressed in order to find the conditional PEP over the channel distribution. The unconditioned PEP can be found by averaging the conditional PEP adopting the MGF approach (Zimon & Aluini, 2005) given as follows:

$$P_E(x) = \frac{1}{\pi}\int_0^{\pi/2} \frac{\prod_{i=0}^{R} H_i(\theta)}{1 + \frac{\gamma_{s,d}}{sin^2\theta}|d_{min}|^2} d\theta \tag{2.18}$$

By manipulating 3.35268 in (Gradshteyn & Ryzhik, 2000),

$$\prod_{i=0}^{R} H_i(\theta) = \int_0^{\infty} \frac{e^{-h_i}}{1 + \frac{\gamma_{s,r_i,d}}{sin^2\theta}|d_{min}|^2} dh_i = e^{\epsilon_i(\theta)}E_1(\,\epsilon_i\,(\theta)) \tag{2.19}$$

where $\epsilon_i\,(\theta)$ can be written as:

$$\epsilon_i\,(\theta) = \frac{4}{\frac{1}{sin^2\theta}\alpha^2_{s,r_i,d}G_i^2|d_{min}|^2 + 2\big(1-\alpha^2_{s,r_i,d}\big)G_i^2P_S + 4G_i^2} \tag{2.20}$$

and $E_1(\beta) = \int_{-\beta}^{\infty}\frac{e^{-t}}{t}dt$ denotes the exponential integral function.

Since the PEP numerical analysis is derived based on the optimum combining weight as in (2.27), it will serve as the lower bound of the system when the proposed combining weights are utilized.

Outage Probability

This section derived the signal received outage probability at the desired destination. The instantaneous SNR in (2.7) and (2.8) is derived. Because of the tedious task in determining the combining weight in (2.13) and (2.14), the optimum combining coefficient, which served as a benchmark under time-varying environment is applied. It is observed that the performance analysis approach is applied similarly as in (Himsoon et al., 2005).

Outage probability is defined as that outage occurs when the instantaneous SNR γ_T received falls below a certain specific threshold γ_{th}. Hence, outage probability is expressed as:

$$P_{out} = \Pr\left(\gamma_T \leq \gamma_{th}\right) \tag{2.21}$$

where the instantaneous SNR γ_T with $\gamma_{s,d}$ and $\gamma_{s,r,d}$ are two independent random variables.

By referring to (Himsoon et al., 2005), the instantaneous SNR received of the direct and relayed links, $\gamma_{s,d}$ and $\gamma_{s,r,d}$ can be represented as:

$$\gamma_{s,d} = \frac{\alpha_{s,d}^2 P_S}{2P_S(1-\alpha_{s.d}^2) + 4 + 2/P_S} \tag{2.22}$$

and

$$\gamma_{s,r,d} = \frac{\alpha_{s,r,d}^2 P_R}{2P_R\left(1-\alpha_{s.r,d}^2\right) + 4 + 2/P_R} \tag{2.23}$$

Since the outage probability for DDAF is the Cumulative Density Function (CDF) of $\gamma_T = F_{\gamma_T}(\gamma_{th})$, then the outage probability of DDAF relaying is:

$$P_{out} = F_{\gamma_T}(\gamma_{th}) \tag{2.24}$$

where the CDF of γ_T is written as:

$$\begin{aligned} F_{\gamma_T}(\gamma_{th}) &= \Pr\left(0 \leq \gamma_T \leq \gamma_{th}\right) \\ &= \int_0^{\gamma_{th}} \Pr\left\{0 \leq \gamma_{s,r,d} \leq x - \gamma_{s,d}\right\} P_{\gamma_{s,d}}\left(\gamma_{s,d}\right) d\gamma_{s,d} \end{aligned} \tag{2.25}$$

The CDF of $\gamma_{s,r,d}$ can be determined as 5.4111 and 12.111 in (Gradshteyn & Ryzhik, 2000) and the outage probability of the DDAF relaying is given as:

$$\begin{aligned} P_{out}(\gamma_{th}) = 1 - e^{-\frac{\gamma_{th}}{\bar{\gamma}_{s,d}}} - \int_0^{\infty} \frac{1}{\bar{\gamma}_{rd}\bar{\gamma}_{s,d}} e^{-\frac{t}{\bar{\gamma}_{r,d}}} \times \Big(\frac{1}{\bar{\gamma}_{s,d}} - \frac{1}{\bar{\gamma}_{s,r}} \\ - \Big(\frac{1+\frac{1}{\bar{\gamma}_{s,r}}}{t}\Big) \times \left(e^{-\left(\frac{1+\frac{1}{\bar{\gamma}_{s,r}}}{t} + \frac{1}{\bar{\gamma}_{s,r}}\right)\gamma_{th}} - e^{-\frac{\gamma_{th}}{\bar{\gamma}_{s,d}}} \right) dt \end{aligned} \tag{2.26}$$

(2.26) is simplified and its closed-form expression can be written as:

$$P_{out}(\gamma_{th}) = 1 - e^{-\frac{\gamma_{th}}{\bar{\gamma}_{s,d}}} - e^{-\frac{\gamma_{th}}{\bar{\gamma}_{s,r}}} \frac{\bar{\gamma}_{r,d}}{\bar{\gamma}_{s,r}\left(1+\frac{1}{\bar{\gamma}_{s,r}}\right)} + 2e^{-\frac{\gamma_{th}}{\bar{\gamma}_{s,r}}} \Big(\frac{\gamma_{th}}{\bar{\gamma}_{s,r}}\Big) K_2\Big(\sqrt{\left(1+\frac{1}{\bar{\beta}_{s,r}}\right)\frac{\gamma_{th}}{\bar{\gamma}_{r,d}}}\Big) \tag{2.27}$$

RESULTS AND DISCUSSION

In this research, the channel gains are substituted by the variances and an MRC is proposed at the destination to bypass the channel and frequency offset estimation. A MSDD AF cooperative network with employing various number of relays is simulated and presented in cases of different fading channels and communication terminals' mobility. All the channels are perturbed with frequency offsets and are generated independently following the mobile-to-mobile wireless communication simulation method of (Himsoon et al., 2005). BER and outage probability are analyzed under slow and fast fading environment. Slow fading Rayleigh channel is adopted employing the normalized Doppler frequency of 0.001. It is then increased to 0.05 as to represent a high mobility scenario.

Conventional MRC and proposed MRC methods employing the derived weight are incorporated into the cooperative wireless networks. The information signal is encoded with DD modulation with Binary Pulse Shift Keying (BPSK) and Quadrature Phase Shift Keying (QPSK) constellations. The signals are transmitted in blocks. Since prior knowledge of the channel is unknown, the relay amplification factor is fixed as $G = (\frac{P_{Ri}}{(P_S+1})^{1/2}$ where P_R and P_S represent the relay power and source power, respectively.

<u>ERROR PROBABILITY PERFORMANCE</u>

Figure 2 compares the BER performance of the conventional MRC and proposed MRC scheme with DDBPSK modulation. The channel variances $\sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 1; \sigma_{s,d}^2 = 1$ and normalized Doppler frequency $f_{D_{s,d}}T_s = f_{D_{s,r}}T_s = f_{D_{r,d}}T_s = 0.05$ representing slow fading environment is considered.

It is observed that the total power P_T is similar to SNR as the normalized variance and AWGN is 1. The received signals are combined at the destination with the weights in (2.9) and (2.10) as well as the optimum combining weights in (2.13) and (2.14) for the Euclidean-distance detection to regain the originally transmitted signals.

Both schemes are simulated and plotted in graph BER versus SNR. It is observed that, the conventional MRC method experiences performance degradation even when slow fading channels are involved. However, when the proposed weight is simulated, it is able to achieve better performance. For instance, the performance gap reduces to 2-3 dB throughout the SNR value. This is because, the new combiner weights in (2.13) and (2.14) depends on the channel fading factor, relay gain and average source power. On the other hand, the conventional MRC assumes only the relay gain. Also, the simulated BER curves with solid lines (different legends) for both combining schemes are compared and plotted with the derived BER numerical analysis (2.18) with dashed lines. It is noted that both simulation results and analytical expression match tightly, even in the low SNR region.

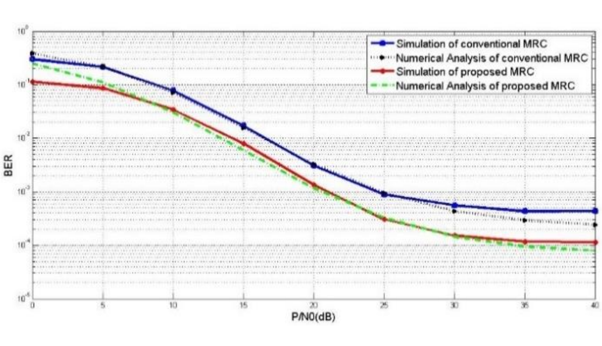
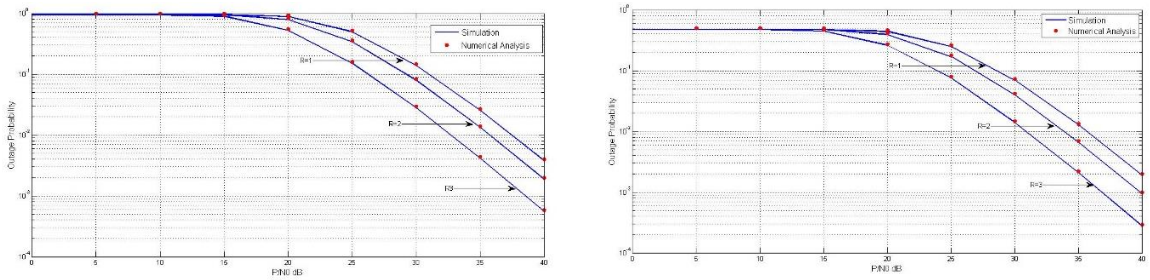


Figure 2. Comparison of the BER performance for conventional MRC and proposed MRC utilizing DDBPSK with 2 relays for $f_{D_{s,d}}T_s = f_{D_{s,r}}T_s = f_{D_{r,d}}T_s = 0.05$

OUTAGE PROBABILITY

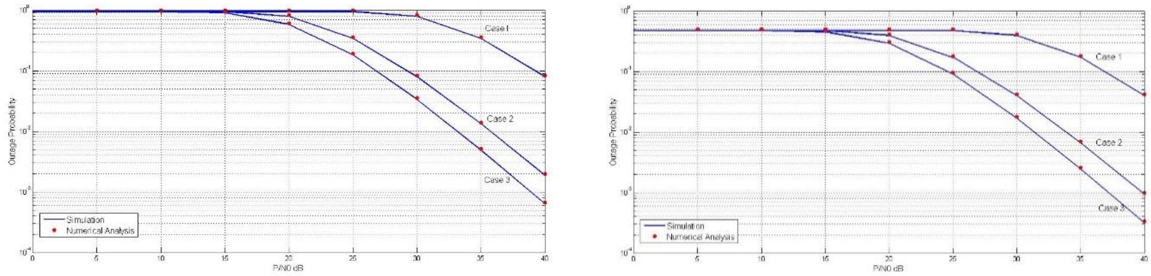
Figure 3 shows the outage probability simulation and its corresponding numerical analysis approximations with the effect of relay configuration applying the proposed MRC. It can be observed also, that the achieved diversity order is dependent on the number of relays and that the outage probability performance analysis can be efficiently forecasted.



(a) (b)

Figure 3. Outage probabilities of the MSDDSD-AF network for (a) BPSK (b) QPSK with proposed MRC employing different numbers of relay terminals

At transmitted power of 40 dB, the relay configuration of 1, 2 and 3 give 0.15, 0.08 and 0.03, respectively. This result reviews that the system outage reduces by an average of 54.59% when the number of relays increase. It is concluded that the diversity order is directly proportional with the number of relays used. In addition, the outage probability analysis is further analyzed under different terminals' mobility environments. From Figure 4, it can be observed that the simulation results are verified by the outage probability derivation with the assumption that $\sigma_{s,r}^2 = 1; \sigma_{r,d}^2 = 1; \sigma_{s,d}^2 = 1$, and the power is equally distributed at both source and relay terminals. The simulation results plotted are employing BPSK and QPSK. At transmitted power of 40 dB, the outage probability of the semi MRC for case I (slow faded), case II (moderately faded) and case III (fast faded) are 0.8, 0.015 and 0.005, respectively. The results show that the proposed MRC for case III has a 66.67% reduced outage probability compared to the MRC in case 2. Thus, it can be concluded that the proposed MRC for fast fading channels give lower outages compare to the case of I and II.



(a) (b)

Figure 4. Outage probability performance of proposed MRC under different faded channels for MSDDSD-AF system for (a) BPSK and (b) QPSK constellation

CONCLUSION

Cooperative communication is a promising technique particularly in mobile communication to provide spatial diversity, increase the cell coverage and improve the error performance. The previous literature studied and focused intensively on the detection whereby full knowledge channel is required. Although under the circumstances for slow fading channels, it is easy to determine the channel knowledge for a single point network, it a challenging to determine both the channel knowledge and frequency offsets accurately under fast fading channels in cooperative communication networks. Therefore, this research proposed and demonstrated that the modified MRC method is capable to produce significant solution for data transmission. The research also revealed that the proposed method outperforms the conventional method using the MSDD approach. The derived performance analysis or error and outage probability also match tightly with the proposed method performance analysis. In this research, frequency offset is considered exists in the relay networks. However, in real practice, several interferences such as Inter Symbol Interference (ISI) and Co-Channel Interference (CCI) would occur. Thus, it is interesting to consider both ISI and CCI under time-varying channels by developing the detection methods to solve the interference effect.

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