3.1 Introduction

This chapter discusses the different cooperative protocols (Amplify and forward (AF), Decode and forward (DF) and Quantize and forward (QF)).This section takes into consideration one relay and multi-relay cooperative communications in wireless networks.

Using Maximal Ratio Combining (MRC) at destination. Analyze the symbol error rate (SER) performance for cooperative systems using M-ary Phase Shift Keying (M-PSK).

3.2 Cooperative System Model

A cooperative strategy is modeled into two phases as shown in Figure 3.1.

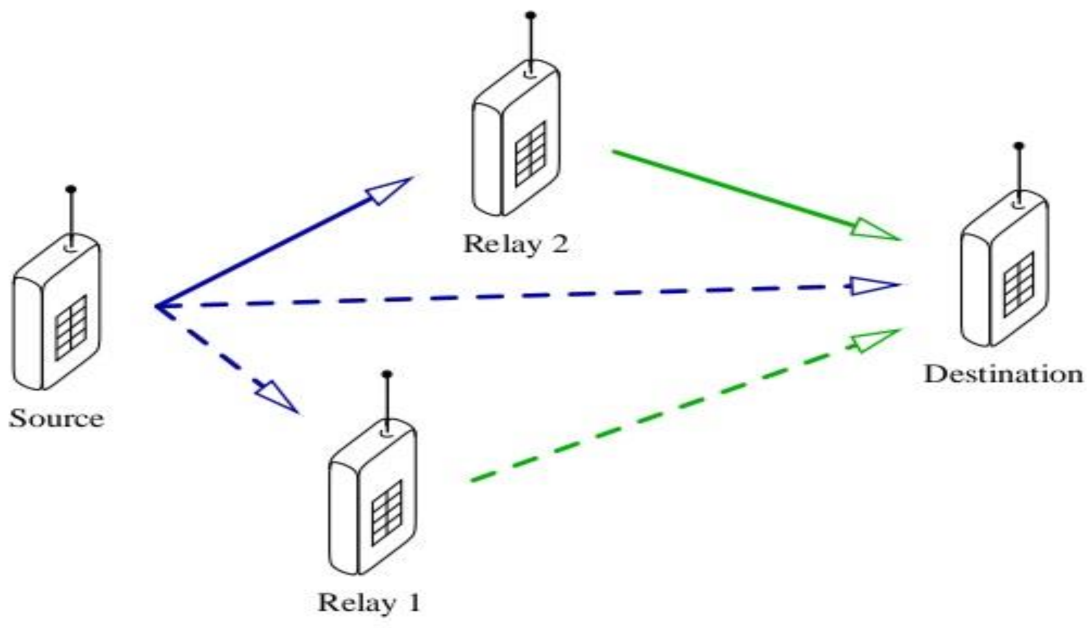

Figure 3.1: Cooperative Communication.

- In phase 1, the source sends (broadcast) information to its destination, and the information is also received by the relay (due to broadcast) at the same time.

The received signal at the destination and the relay, can be written as:

$$y_{s,d} = \sqrt{P_1}\, h_{s,d}\, x + \eta_{s,d} \tag{3.1}$$

$$y_{s,r_i} = \sqrt{P_1}\, h_{s,r_i} x + \eta_{s,r_i} \tag{3.2}$$

Where:

P_1 = the total power transmitted at the source.

x = the transmitted information Symbol.

$\eta_{s,d}$ & η_{s,r_i} = additive white Gaussian Noise from the source to destination and from the source to relay link respectively.

$h_{s,d}$ & h_{s,r_i} = The channel coefficients are given for the source to destination and source to relay link respectively.

- In phase 2 the relay can help the source by forwarding or retransmitting the Information to the destination [9].

3.3 Performance of Cooperative Protocols

3.3.1 Amplify and Forward Protocol

In this case the relay forwards the information received from the sender during phase 1 and it amplifies and retransmit the signal to its destination during the phase 2. In doing so, noise also get amplified, which is the major drawback of this method [4].

The received signal at the destination from the relay is:

$$y_{r_i,d} = \frac{\sqrt{P_2}}{\sqrt{P_1 \left|h_{s,r_i}\right|^2 + \mathcal{N}_0}}\, h_{r_i,d}\, y_{s,r_i} + \eta_{r_i,d} \tag{3.3}$$

Where:

$h_{r_i,d}$ = the coefficient of relay to destination channel, and it is modeled as a zero-mean complex Gaussian random variable with variance $\delta^2_{r_i,d}$.

$\eta_{r_i,\mathrm{d}}$ = The noise of the relay to the destination channel. It is also modeled as a zero-mean complex Gaussian random variable with variance $\mathcal{N}_0$.

$\mathrm{y}_{\mathrm{s,r_i}}$ = The received signal from the source to the relay.

For more specifically it can be:

$$y_{r_i,d} = \frac{\sqrt{P_1\, P_2}}{\sqrt{P_1 \left|h_{s,r_i}\right|^2 + \mathcal{N}_0}}\, h_{r_i,d}\, h_{s,r_i}\, x + \eta'_{\mathrm{r_i,d}} \tag{3.4}$$

Where:

$$\eta'_{\mathrm{r_i,d}} = \frac{\sqrt{P_2}}{\sqrt{P_1 \left|h_{s,r_i}\right|^2 + \mathcal{N}_0}}\, h_{r_i,d}\, \eta_{s,r_i} + \eta_{r_i,d} \tag{3.5}$$

Assume that the noise terms η_{s,r_i} & $\eta_{r_i,d}$ are independent, then the equivalent noise $\eta'_{\mathrm{r_i,d}}$ is a zero-mean complex Gaussian random variable with variance:

$$\left(\frac{P_2\, \left|h_{\mathrm{r_i,d}}\right|^2}{P_1\, \left|h_{\mathrm{s,r_i}}\right|^2 + \mathcal{N}_0} + 1\right) \mathcal{N}_0 \tag{3.6}$$

In the AF cooperative systems, the relay amplifies not only the received signal but also the noise [11].The combined signal at the MRC detector given by:

$$y = a_1\, \mathrm{y_{s,d}} + a_2\, \mathrm{y}_{r_i,\mathrm{d}} \tag{3.7}$$

In which the factors a_1 and a_2 are determined such that the SNR of the MRC output is maximized, and can be specified as:

$$a_1 = \frac{\sqrt{P_1}\, h^*_{s,d}}{\mathcal{N}_0} \tag{3.8}$$

$$a_2 = \frac{\frac{\sqrt{P_1\, P_2}}{\sqrt{P_1 \left|h_{s,r_i}\right|^2 + \mathcal{N}_0}}\; h^*_{s,r_i} h^*_{r_i,d}}{\left(\frac{P_2\,\left|h_{\mathrm{r_i,d}}\right|^2}{P_1\,\left|h_{\mathrm{s,r_i}}\right|^2 + \mathcal{N}_0} + 1\right)\mathcal{N}_0} \tag{3.9}$$

The transmitted symbol *x* in (3.1), (3.2) has average energy 1, then the SNR of the MRC output is:

$$\gamma = \gamma_s + \sum_{i=1}^{n} \gamma_{r_i} \tag{3.10}$$

$$\gamma_s = \frac{P_1\,|h_{s.d}|^2}{\mathcal{N}_0} \tag{3.11}$$

$$\gamma_{r_i} = \frac{\frac{P_1\,P_2}{P_1\left|h_{s.r_i}\right|^2 + \mathcal{N}_0}\left|h_{s.r_i}\right|^2\left|h_{r_i.d}\right|^2}{\left(\frac{P_2\left|h_{\mathrm{r_i,d}}\right|^2}{P_1\left|h_{\mathrm{s,r_i}}\right|^2 + \mathcal{N}_0} + 1\right)\mathcal{N}_0} \tag{3.12}$$

$$\gamma_{r_i} = \frac{1}{\mathcal{N}_0}\,\frac{P_1\,P_2\left|h_{s.r_i}\right|^2\left|h_{r_i.d}\right|^2}{P_1\left|h_{\mathrm{s,r_i}}\right|^2 + P_2\left|h_{\mathrm{r_i,d}}\right|^2 + \mathcal{N}_0} \tag{3.13}$$

The conditional SER of AF cooperative systems with M-PSK modulations can be given as follows:

$$P_{PSK}^{h_{s,d},h_{s,r_i},h_{r_i,d}} \approx \frac{1}{\pi}\int_0^{(M-1)\,\pi/M} exp\left(-\frac{b_{PSK}\,(\gamma)}{sin^2\theta}\right) d\theta \tag{3.14}$$

Where $b_{psk} = sin^2(\pi/M)$

3.3.2 Decode and Forward Protocol

For a decode and forward cooperative protocol, if the relay is able to decode the transmitted symbol correctly, then the relay forwards the decoded symbol to the destination, otherwise the relay does not send or remains idle. The received signal at the destination from the relay is:

$$\mathrm{y}_{r_i,\mathrm{d}} = \sqrt{\tilde{p}_2}\, h_{\mathrm{r_i,d}}\, \mathrm{x}_{r_i} + \eta_{r_i,\mathrm{d}} \tag{3.15}$$

Where:

$\tilde{p}_2$ = the transmission power of the relay. When $\tilde{p}_2 = P_2$ if the relay decode the transmitted symbol correctly, otherwise $\tilde{p}_2 = 0$.

$h_{\mathrm{r_i,d}}$ = the coefficient of the relay to the destination channel, and it is modeled as a zero-mean complex Gaussian random variable with variance $\delta^2_{r_i,d}$.

x_{r_i} = is the transmitted information symbol form relay.

$\eta_{r_i,\mathrm{d}}$ = The noise of relay to destination channel. It is also modeled as a zero-mean complex Gaussian random variable with variance $\mathcal{N}_0$.

Consider the SER performance analysis for the DF cooperative communication systems in closed-form SER formulations for the systems with *M*-PSK [5].

The combined signal at the MRC detector is given by:

$$y = a_1\, \mathrm{y}_{\mathrm{s,d}} + a_2\, \mathrm{y}_{r_i,\mathrm{d}} \tag{3.16}$$

In which the factors a_1 and a_2 are determined such that the SNR of the MRC output is maximized, and they can be specified as:

$$a_1 = \sqrt{p_1}\, h^*_{s,d} \big/ \mathcal{N}_0 \tag{3.17}$$

$$a_2 = \sqrt{\tilde{p}_2}\, h^*_{r_i,d} \big/ \mathcal{N}_0 \tag{3.18}$$

The transmitted symbol *x* in (3.1), (3.2) has average energy 1, then the SNR of the MRC output is:

$$\gamma = \frac{P_1\ \left|h_{s,d}\right|^2 + \sum_{i=1}^{n} \tilde{p}_2 \left|h_{r_i,d}\right|^2}{\mathcal{N}_0} \tag{3.19}$$

Symbol Error Rate (SER) formulations for an un-coded system with *M*-PSK ($M = 2^K$ with *k* even) modulation [9][12], which are given by

$$\psi_{PSK} \triangleq \frac{1}{\pi}\int_0^{(M-1)\,\pi/M} exp\left(-\frac{b_{psk}\,\gamma}{sin^2\theta}\right) d\theta \tag{3.20}$$

Where: $b_{psk} = sin^2(\pi/M)$

3.3.3 Quantize and Forward Protocol

In quantize-and-forward transmission, instead of sending an amplified version of the $\mathrm{y}_{\mathrm{s,r_i}}$, the relay detects the phase of $\mathrm{y}_{\mathrm{s,r_i}}$, performs uniform quantization with *q* bits and transmits a PSK signal with the quantized phase and same power as the source's transmission. To reduce the processing burden at the relay, the detected phase is assumed to include the effect of channel rotation n and the relay's phase offset [9].

The received signal at the destination from the relay is:

$$y_{r_i,d} = h_{\mathrm{r_i,d}} e^{j\angle^{\wedge} y_{s,r_i}} + \eta_{r_i,\mathrm{d}} \tag{3.21}$$

Where:

$\eta_{r_i,\mathrm{d}}$ = the noise contribution from the relay to destination.

$h_{\mathrm{r_i,d}}$ = the overall channel attenuation, including the effects of distance and fading from the relay to destination.

Where $\angle^{\wedge} y_{s,r_i} \in \{\emptyset_0, \emptyset_1, \ldots\ldots\ldots, \emptyset_{2^q-1}\}$ denotes the quantized phase of the source-relay signal y_{s,r_i} , with uniform quantization

$$\angle^{\wedge} y_{s,r_i} = \emptyset_{\mathrm{k}} = {}^{2\pi\mathrm{k}}/_{2^{\mathrm{q}}} \text{ if } \angle^{\wedge} y_{s,r_i} \text{ is within}$$

$$\frac{\pi}{2^{\mathrm{q}}}(2\mathrm{k}-1) \,.< \angle y_{s,r_i} \leq \frac{\pi}{2^{\mathrm{q}}}(2\mathrm{k}+1)\,, \quad \mathrm{k} = 0,1,\ldots\ldots.,2^{\mathrm{q}}-1.$$

The average value of the instantaneous signal to noise ratio (SNR) are given as:

$$\gamma_{\mathrm{s}} = \left|h_{s,d}\right|^2 P_1 \tag{3.22}$$

$$\gamma_{\mathrm{r_i}} = \left|h_{\mathrm{r_i,d}}\right|^2 P_2 \tag{3.23}$$

$$\gamma = \gamma_s + \sum_{i=1}^{n} \gamma_{r_i} \tag{3.24}$$

The conditional SER of QF relay protocol with M-PSK modulations can be given as follows:

$$P_{PSK}^{h_{s,d},h_{s,r_i},h_{r_i,d}} \approx \frac{1}{\pi}\int_0^{(M-1)\,\pi/M} exp\left(-\frac{b_{PSK}\ \gamma}{sin^2\theta}\right) d\theta \tag{3.25}$$

Where $b_{psk} = sin^2(\pi/M)$