Noncoherent Detection Techniques in Cooperative Relaying Using Generalized Likelihood Ratio Test

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Introduction

- Cooperative diversity has been introduced as an efficient mean to combat the effects of multipath fading in wireless channels.
- Amplify-and-forward has shown to provide full spatial diversity when global knowledge of Channel State Information (CSI) is available at the destination.
- The availability of perfect knowledge of CSI may not be practical.
- It is interesting to consider the case when either partial or no CSI is available at the receiving node.

Noncoherent Detection Approach

- Bayesian approach:
  - Considers unknown channel parameters as realizations of random variables with known statistics.
  - Optimally exploits channel statistics information.
  - Requires multiple integration.
- Generalized Likelihood Ratio Test (GLRT) approach:
  - Uses maximum likelihood estimate (MLE) of the unknown parameters.
  - Does not necessarily guarantee optimality.
  - Less strict assumptions.

Cooperating System Model

- The cooperating system is modeled by N nodes, where node No. 1 is the source node, node No. N is the destination node and all other (N-2) nodes are cooperating nodes in an Amplify and Forward (AF) transmission scheme.
- For AF, the relay simply amplifies the received signal y_{1i} by a factor A_i and forward it to the destination.
- The amplification factors are determined by one of the following:
  - Constant Amplification (CA) : $$A_i = \sqrt{\frac{E_i}{E_1 G_{1i} + N_0}} \quad (1)$$
  - Constant Power (CP): $$A_i = \sqrt{\frac{K E_i}{|y_{1i}|^2}} \quad (2)$$

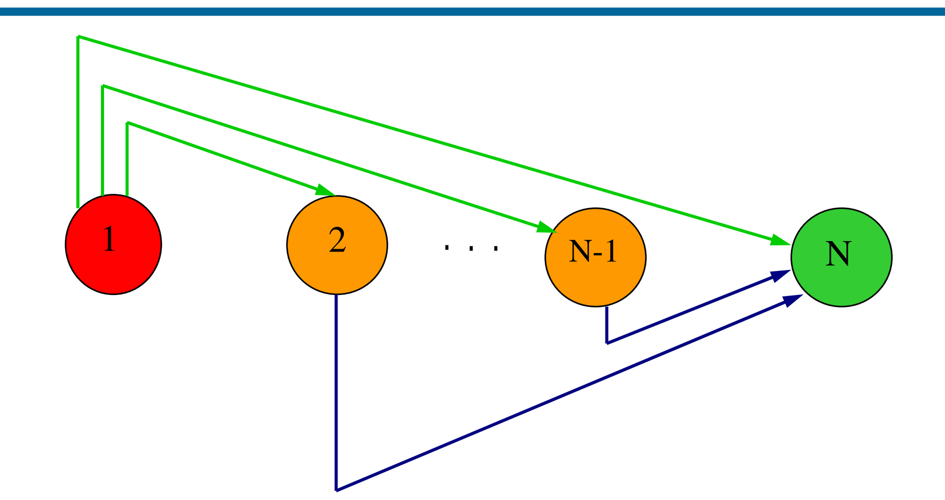

Fig. 1: General system model

- This system, with some modification, can be modeled as a multichannel wireless communication operating over L independent, flat fading, branches.

Multichannel System Model

- The signal model for multichannel reception of L branches, where the signal received from the lth branch is given by $r_{l,k} = h_l s_k + n_{l,k}$, where s_k is the transmitted signal, h_l is the channel gain of the lth branch and $n_{l,k}$ is the additive Gaussian noise.
- The vector notation of the signal model is: $\mathbf{r}_l = h_l \mathbf{s} + \mathbf{n}_l$ (3)

  Where $\mathbf{r}_l=(r_{l,1}, r_{l,2}, \cdots, r_{l,K})^T$, $\mathbf{s}=(s_1, s_2, \cdots, s_K)^T$, and $n_l=(n_{l,1}, n_{l,2}, \cdots, n_{l,K})^T$. Noise samples are assumed to be independent in respect with l and k. The noise variance σ_l^2 are not necessarily equal.
- The conditional probability function (pdf),
$$p(\{r_l\}_{l=1}^L \mid s, \{h_l\}_{l=1}^L, \{\sigma_l^2\}_{l=1}^L) = \prod_{l=1}^{L} \frac{1}{(\pi\sigma_l^2)^K} \exp\left(-\frac{\|r_l - s h_l\|^2}{\sigma_l^2}\right) \quad (4)$$
  is used next to derive the GLRT based detection scheme.

GLRT based detection (1)
Minimum Weighted Sum of Squared Errors (MWSE)

- **Case 1:** Unknown channel gains and known noise variance.
- In this case the GLRT detector is given by:
$$\hat{i} = \arg\max_i \max_{\{h_l\}_{l=1}^L} p(\{r_l\}_{l=1}^L \mid s, \{h_l\}_{l=1}^L, \{\sigma_l^2\}_{l=1}^L) = \arg\max_i \prod_{l=1}^{L} \frac{1}{(\pi\sigma_l^2)^K} \exp\left(-\frac{\left\| r_l - s\hat{h}_l^{(i)} \right\|^2}{\sigma_l^2}\right) \quad (5)$$
- Using maximal-likelihood to find the estimated value of h_l , assuming s_i is sent, we get:
$$\hat{h}_l^{(i)} = \arg\max_{h_l} p(r_l \mid s_i, h_l, \sigma_l^2) = \frac{s_i^H r_l}{|s_i|^2} \quad (6)$$
- The GLRT detector chooses the signal s_i that **minimizes**:
$$\eta(s_i) = \sum_{l=1}^{L} \frac{1}{\sigma_l^2} e_l(s_i) \quad (7)$$
  Where:
$$e_l(s_i) = |r_l|^2 - \frac{|s_i^H r_l|^2}{|s_i|^2} \quad (8)$$
- Therefore, this detector is called minimum weighted sum of squared errors (MWSE).

GLRT based detection (2)
Minimum Product of Squared Errors (MPSE)

- **Case 2:** Unknown channel gains and unknown noise variance.
- In this case we need to use maximal likelihood to estimate both the value of h_l and σ_l^2 .
- For σ_l^2 we get:
$$\hat{h}_l^{(i)} = \frac{s_i^H r_l}{|s_i|^2} \quad ; \quad \hat{\sigma}_l^{2(i)} = \frac{1}{K}\left\| r_l - s_i \hat{h}_l^{(i)} \right\|^2 \quad (9)$$
- The GLRT detector chooses the signal s_i that **minimizes**:
$$\eta(s_i) = \prod_{l=1}^{L}\left[|r_l|^2 - \frac{|s_i^H r_l|^2}{|s_i|^2} \right] = \prod_{l=1}^{L} e_l(s_i) \quad (10)$$
- Therefore, this detector is called minimum product of squared errors (MPSE).

Simulation Results

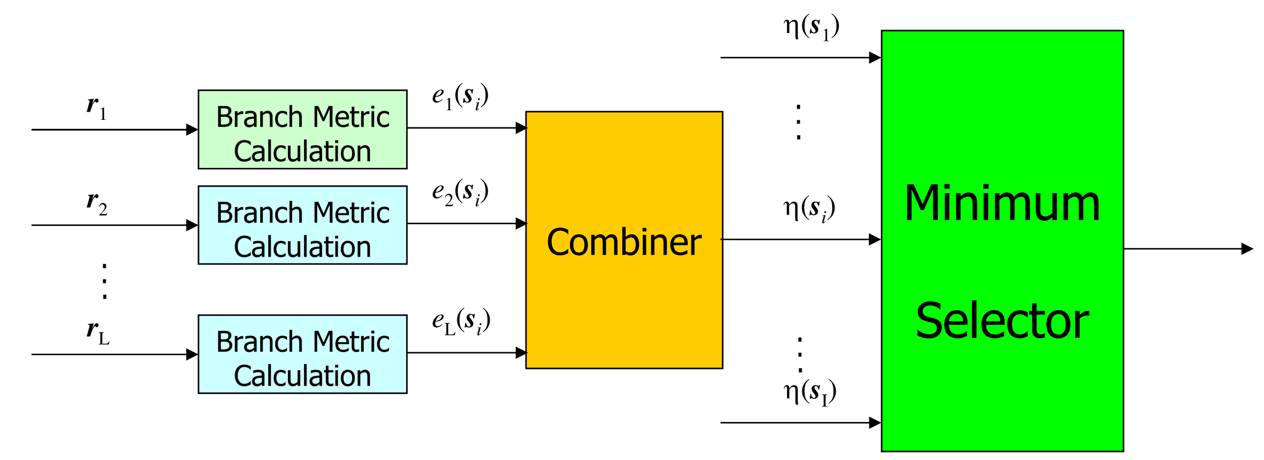

Fig. 2: Unified structure of the GLRT based detector

- **Simulation assumption**:

  Binary DPSK is used. The total transmit power $E_t = E_1 + (N-2)E_R$. Relays are located on the straight line passing through source and destination. Location of node i is determined by its normalized distance to the source.

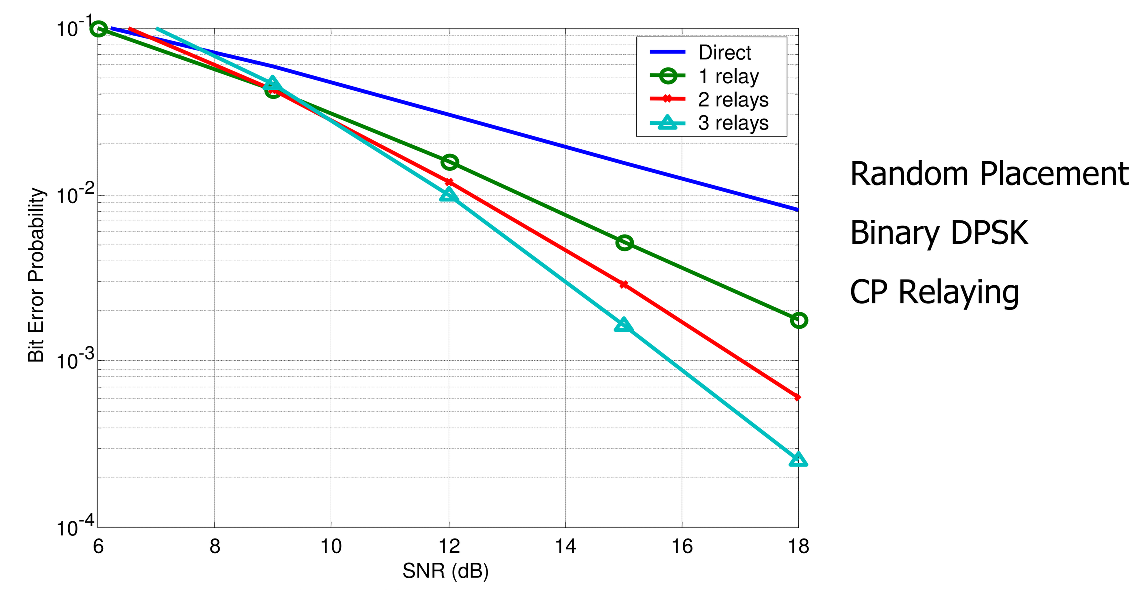

Fig. 3: Bit error Probability for different transmission schemes: when direct transmission is employed or cooperation with 1,2, or 3 relays is employed

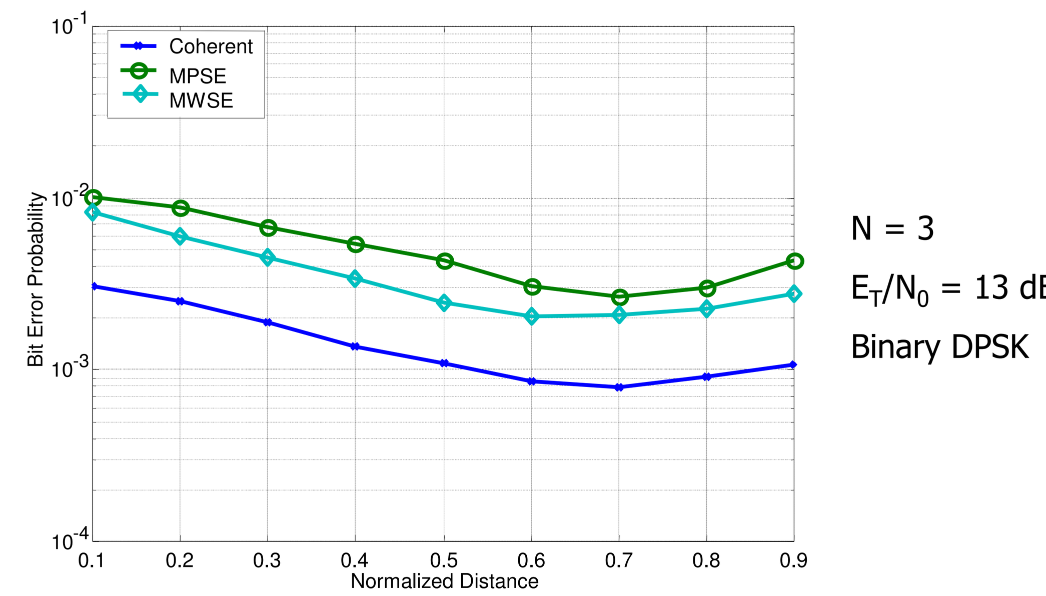

Fig. 4: Bit error Probability as a function of distance for the proposed MWSE and MPSE schemes and the coherent case

Conclusions

- Two GLRT based detection algorithms are proposed, MWSE and MPSE, for noncoherent detection.
- This approach provides complexity reduction in the detector realization.
- It is shown that cooperative AF with GLRT based noncoherent detection performs better than direct transmission from source to destination.
- These algorithms are robust to the location of the relay nodes.

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