Relay Selection Schemes for Cooperative Communications Systems Sensor Networks

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Abstract

Due to being so effective to mitigate the fading effect of wireless channels relay networks have received so much attention recently. Especially because relays are typically small, power limited and low cost and also can remove the problem of attenuation of signal due to propagation loss. Moreover increasing the number of relays improves the system performance and also using more power. The system efficiency can be enhanced by selecting relays in better conditions. In this paper single and multiple relay selection schemes is proposed applying Principal Component Analysis (PCA) method. The main idea of PCA method is selecting relays according to the eigenvector corresponding to the largest eigenvalue of channels from source to the destination. The PCA method provides an acceptable tradeoff between better power and Bit Error Rate (BER) performances. The higher efficiency is achieved by Appling PCA which demonstrated in power performance and this management of total power usage makes relay networks more practical.

Keywords: Amplify-forward scheme, Relay network, PCA, Relay selection

1. Introduction

In wireless networks one of the problems is to deal with high data rate services due to path loss and fading effect. Path loss is the attenuation in the amplitude of the signal when it is sent from the transmitter to the receiver. However in wireless channels, along with path loss, fading also affects the signal quality. When signal components received over different propagation paths add destructively called fading which decreases the performance of the wireless network (Proakis J. G. 2000). So to provide a reliable transmission, it needs to compensate for the effect of signal fading due to either multipath propagation or strong shadowing (Shahan Behbahani A., Merched R. and Eltawil A. M. 2008).

One of the most effective ways to mitigate the fading effect of wireless channels in a network is diversity. Diversity is the way to improve capacity or reliability of a wireless network. Diversity can be categorized into three groups: time diversity, frequency diversity and spatial diversity (Borade Sh., Zheng L. and Gallager R. 2007). Time diversity is transmitting the same signal over different time slots, frequency diversity is transmitting the same signal over a large bandwidth and spatial diversity is transmitting or receiving the same signal over multiple antennas. Spatial diversity can be performed through either antennas or relay sensors. Relays are small, power limited and low cost so they bring us cheaper and shorter-range communications and also bring spatial diversity to the wireless network (Khajehnouri N. and Sayed A. H. 2007).

As a result, relay networking has received considerable attention in the literature, with several works. An early study of relay network and cooperative communications could receive from (Cover T. and Gamal A. E. 1979). The contributions (Intanagonwiwat C., Estrin D., Govindan R., and Heidemann J. 2002; Madden S., Franklin M. J., Hellerstein J. M., and Hong W. 2002) proposed approaches that reduce the volume of data through some aggregation techniques.

Relay schemes can be categorized into three general groups: amplify-forward (AF), compress-forward and decode-forward scheme. In the amplify-forward scheme, the relay nodes amplify the received signal and rebroadcast the amplified signals toward the destination node (Kramer G., Gastpar M., and Gupta P. 2003; Khojastepour M. A., Sabharwal A., and Aazhang B. 2003). In the decode-forward, each relay decodes the entire received message, re-encoded it and sends the resulting sequence to the destination node (Laneman J. N., Tse D.

N. C., and Wornell G. W. 2004 ; Laneman J. N. and Wornell G. W. 2003). In compress-forward, the relay node sends a quantized version of received signal to the destination node (Kramer G., Gastpar M., and Gupta P. 2005). In all categories the network performance can be improved by selecting the proper relays (Jing Y., Jafarkhani H. 2009). There is good research in literature on relay selection schemes (Sadek A. K., Han Z., and Liu K. J. R. 2006 ; Zhao Y., Adve R., and Lim T. J. 2007).

In this paper, it is worked on single and multiple relay selection schemes on networks with parallel AF relays. It is assumed that each relay only knows its own channels but the receiver knows all channel values. First principal component analysis (PCA) is derived on channels from the source node to the relay nodes and select relays related to proper channels then making cooperative diversity with those relay nodes over MMSE relay strategies in a dual-hop AF protocol. There is a relay selection scheme for decode-forward scheme in (Laneman J. N. and Wornell G. W. 2003).

This paper is organized as follows. In the section II, the relay network model is described in details. Then in section III, the idea of single and multiple relay selection scheme applying PCA method is proposed. Section IV contains the simulation results and the paper is concluded in section V.

2. Relay Network Model

As illustrated in Fig. 1, consider a sensor network with n relay nodes between a source node and a destination node. It is supposed there are no connections between relay nodes and relay matrix, K, is diagonal. F denotes the $n \times 1$ (column) channel vector between the source and the relay nodes, and G denotes $1 \times n$ (row) channel vector between the relay sensors and the destination sensor and there is no direct link between source node and destination node. A quasi-static fading condition is assumed for each channel gain so that the channel realizations stay fixed for the duration of a single frame of data. A simple two-phase protocol is used to transmit data from the source sensor to the destination sensor. The first phase is the broadcasting phase, during which the source sensor broadcasts a signal towards the relay sensors. The second phase is the relaying phase, during which the relay sensors transmit their signals to the destination sensor. It is assumed synchronous transmission and reception at relays nodes, so that the relay nodes relay their data at the same time instant and the relay nodes are in the same distance from the source node and the destination node. Suppose each node in the sensor network, source, relays and destination have one antenna. The relay matrix is calculated with MMSE method.

The received scalar signal at the destination sensor is then given by

$$d = GKFs + GKv_s + v_t \tag{1}$$

In (Khajehnouri N. and Sayed A. H. 2007) relay matrix is selected to minimize the mean-square error (mse) between the uncorrupted received signal and a scaled multiple of the transmitted signal:

$$\hat{K} = arg\ \min_K J(K) \tag{2}$$

where

$$J(K) = E\|\eta s - GKFs - GKv_s\|^2 \tag{3}$$

bellow choice would minimize the mse between $h_t x$ and s itself. More generally, the choice

$$\eta_m = \sqrt{SNR_{t,m} \frac{\sigma_{v_t}^2}{\sigma_s^2}} \tag{4}$$

where

$$\sigma_s^2 = E|s|^2 \tag{5}$$

ensure certain a target SNR at the destination node. As a result, it is assumed that each node only has access to local channel information. Specifically, every node will only have access to the channel gains and that connect it to the source and the destination. Thus it shall be selected *diagonal* entries such that:

$$\hat{f}_i = \eta\left(\frac{\sigma_s^2}{\sigma_{n_r}^2 + \sigma_s^2\|F\|^2}\right)\frac{f_i^* g_i^*}{|g_i|^2} \tag{6}$$

3. Relay Selection Applying PCA Method

For K vector samples from a random population, the mean vector can be approximated from the samples by using the familiar averaging expression below:

$$m_x = \frac{1}{K}\sum_{k=1}^{K} x_k \tag{7}$$

It would be found that the covariance matrix can be approximated from the samples as follows:

$$C_x = \frac{1}{K}\sum_{k=1}^{K} x_k x_k^T - m_x m_x^T \tag{8}$$

Because C_x is real and symmetric, finding a set of n orthonormal eigenvectors always is possible (Gonzalez R. C., and Woods R. E. 2008). Let e_i and λ_i , $i = 1, 2, \ldots, n,$ be the eigenvectors and corresponding eigenvalues of C_x , ordered so that the first row of A is the eigenvector corresponding to the largest eigenvalues, and the last row is the eigenvector corresponding to the smallest eigenvalues. Consider below transformation:

$$y = A(x - m_x) \tag{9}$$

Because the rows of A are orthonormal vectors (Gonzalez R. C., and Woods R. E. 2008), it follows that $A^{-1} = A^T$, and any vector x can be recovered from its corresponding y by using the expression:

$$x = A^T y + m_x \tag{10}$$

Suppose, however, that instead of using all the eigenvectors of C_x , matrix A_k is formed from the k eigenvectors corresponding to the k largest eigenvalues, so the vector reconstructed by using A_k is:

$$\hat{x} = A_k^T y + m_x \tag{11}$$

It is approved the PCA transform is optimal in the sense that it minimizes the mean square error between the vectors x and their approximation. The error of this approximation can be calculated as follows:

$$e_{ms} = \sum_{j=1}^{n}\lambda_i - \sum_{j=1}^{k}\lambda_i = \sum_{j=k+1}^{n}\lambda_i \tag{12}$$

Now consider each component of a channel vector as a dimension of transmitted signal so it is reduced according to the eigenvector of the channels corresponding to the largest eigenvalues, actually it is the main idea. As proposed in this paper, this property is used to somehow relay selection (indeed signal dimension reduction) in distributed relay network. The largest eigenvalue of channel vector is the largest variance in the direction of corresponding eigenvector. Thus PCA takes the first k most important components of dimensions of signal. When a signal travels from the source node to the destination node because of relay nodes it gets dimensions through different channels called spatial diversity:

$$s_r = Fs \tag{13}$$

For dual-hop protocols, the relay nodes amplify their received signal and send it to the destination node simultaneously so if some relays received signal with low SNR because of additive Gaussian noise of their channels then the signal can be attenuated more through those channels so relays are selected according to the proper channels from the source node to the relay nodes. In this paper PCA method applied to select the relay or relays which cooperate on the network with MMSE strategies and the network with conventional amplify and forward relay matrix. Consider channels from source node to the relay nodes which its eigenvector corresponding to the largest eigenvalue is calculated. Due to amplifying the received signal by relay nodes with no condition so it is better to select channels from source node to relay nodes.

$$m_F = \frac{1}{n} \sum_{k=1}^{n} F_k \tag{14}$$

$$C_F = \frac{1}{n} \sum_{k=1}^{n} F_k F_k^T - m_F m_F^T \tag{15}$$

As there are n relays and each relay has two choices, there are $2^n \quad 1$ possibilities. Since the receiver knows all the channels, it can find the pca solution. In the conventional amplify and forward network or networks with a limited power for each relay also pca method is applied to select relays and get better power performance. The total power usage of the network is calculated as

$$P_T = \sum_{i=1}^{n} |k_i|^2 \left(\sigma_s^2 |f_i|^2 + \sigma_{v_s}^2\right) \tag{16}$$

4. Simulation Results

In this section the performance of the proposed scheme are simulated for a relay network with one source node and one destination node. It is assumed that all relay nodes are at the same distance from the source and destination sensors and there is no direct link between source and destination. Using this assumption, the channels from the source to the relay nodes have the same second moment statistics as the channels from the relay nodes to the destination node. Zero-mean unit variance complex Gaussian channel models for F and G is used, and the transmitted signal from the source sensor is assumed to be QPSK with unit power. The BER and power performance criterions are chosen to evaluate the performance of the proposed scheme. In Fig. 2, the BER performance of selecting one relay from an 8 relay-network with MMSE relay matrix is shown in two different ways one is the way to select by pca method and another is to select relay by best backward channel selection method and as it is shown pca method has better BER performance. In Fig. 3, the power performance of selecting one relay of an 8- relay network is shown and the better power performance is achieved. In Fig. 4, it can be seen BER performance of selecting 4 relays of an 8-relay network in two different ways, one from pca and another from best backward channel selection and get better performance with applying pca. In Fig. 5, the power performance of 4 relays and 8 relay is shown and the better performance of power usage is achieved. It comes from simulation result that if relays whose channels are in better condition is selected for signal to travel in the wireless sensor network it would be a good trade-off between BER and power performance. It can be seen that, as the number of selected relays increases, the better result is achieved, losing BER less and getting power performance better. It is maybe asked that PCA matrices operation get higher order if the number of relays increases it is true but there is a way to deal with this calculation problem and that is applying EM algorithm for PCA operations. In Fig. 6, it is shown the BER performance of selecting one, 3 and 5 relays of an 8-relay network with conventional relay matrix which each relay has own power constraint as it is shown with selecting more relays could get better performance. This network is simulated with the same power constraint for each relay so total power usage is proper to number of relays which cooperate in the network. In Fig. 7, the BER performance of selecting one, 5 and 8 relays of a 15-relay network is shown with limited total power usage and the BER performance of a network with 8 relays cooperation is so close to the BER performance of a network with15 relays cooperation in the network.

5. Conclusion

In this paper, it is worked on relay network with dual-hop protocol which the relay sensors do not need to share information about the received signals. It was discussed about principal component method and applying it to the relay network as a single and multiple relay selection schemes. Actually one or more relays of n relays were selected and the performance has shown to improve as the number of selection increases. The proposed relay selection scheme with pca method makes a good trade-off between the BER and power performance.

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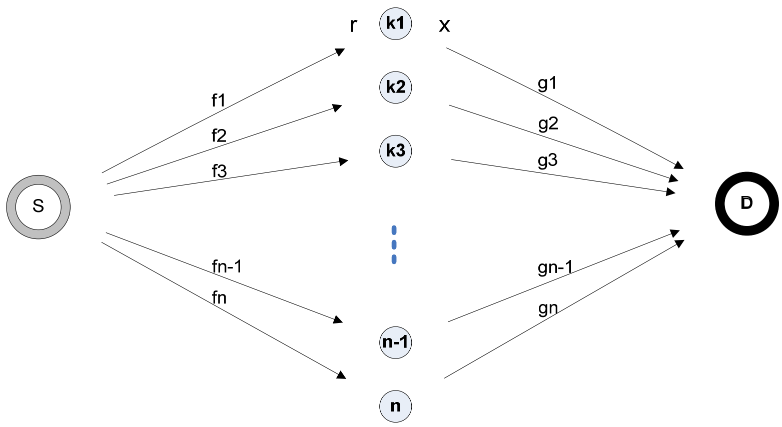

Figure 1. scheme of a n-relay network with one source and one destination

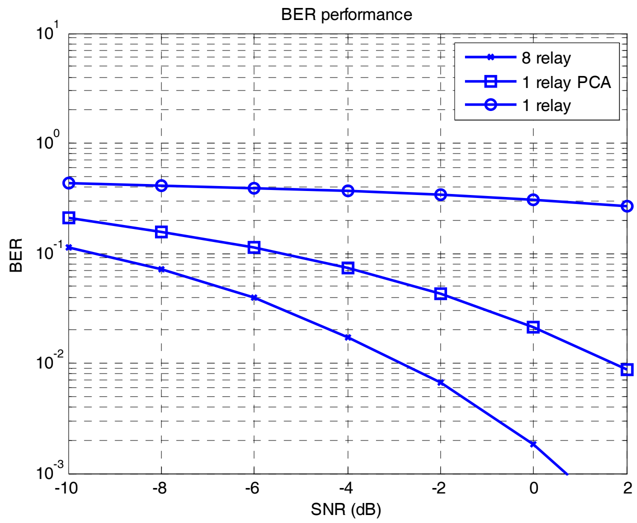

Figure 2. The relay network with 8 relay and selecting one relay

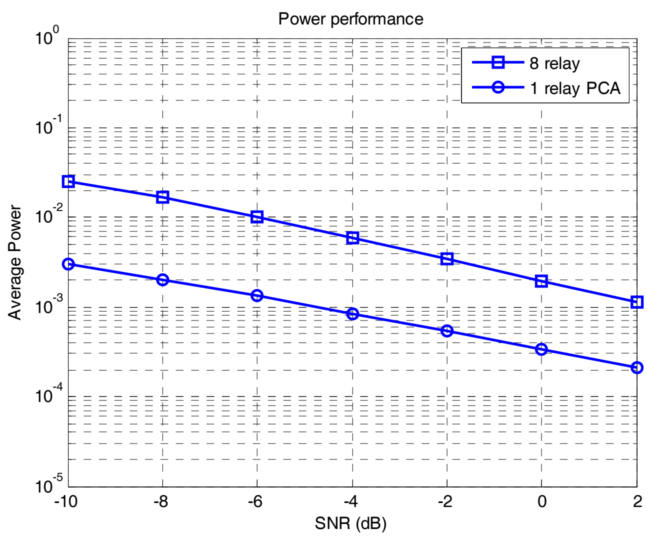

Figure 3. Comparing power performance of 8 relays and one

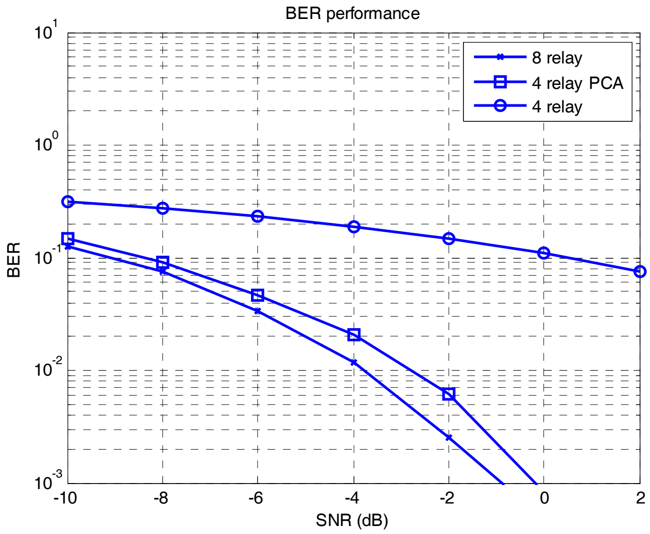

Figure 4. The relay network with 8 relay and selecting 4 relay

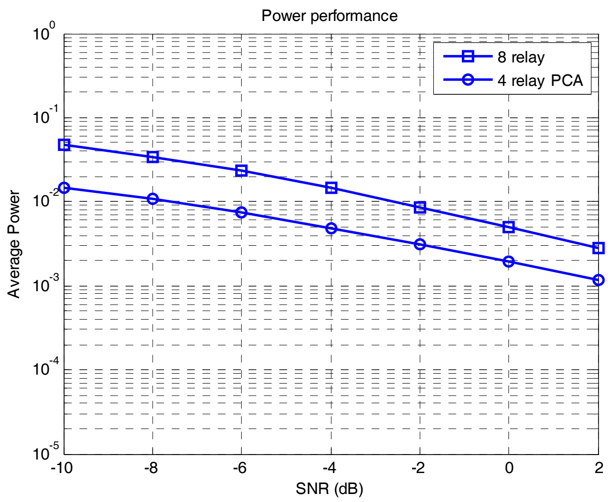

Figure 5. Comparing power performance of 8 relays and 4 relays

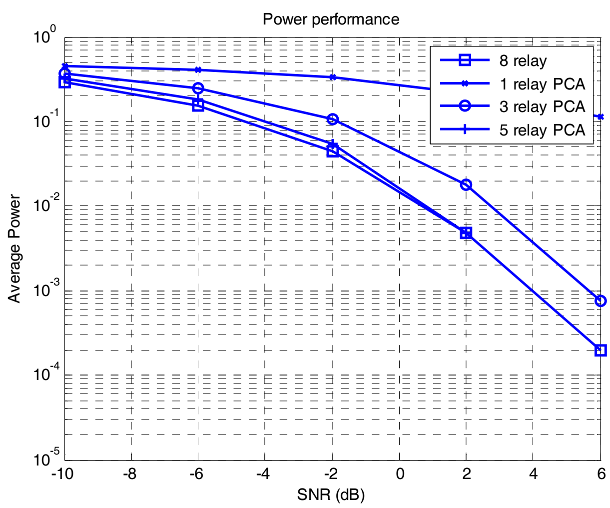

Figure 6. Selecting relays in an 8-relay networks with conventional relay matrix

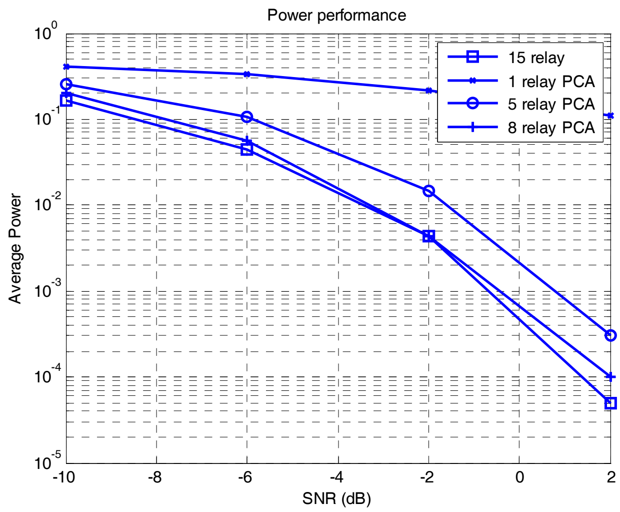

Figure 7. Selecting relays of an 15-relay network with limited total power