Joint Optimization of SINR and Power Allocation to Relays in Cluster-Based Wireless Sensor Networks

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***Abstract*—Wireless relaying has attracted dramatic attention in the last few years due to its advantage in multi-hop communication systems. Cooperation among nodes in a network enhances the overall system performance. Power allocation schemes have been discussed with respect to optimization of signal to noise ratio (SNR) without considering the interference. The contribution of our present approach is to allocate power to relay nodes in presence of interference, for cluster-based cooperative wireless sensor networks (WSNs). In this paper, we consider optimization of the signal-to-interference plus noise ratio (SINR) and allocating the power to relay nodes by using the difference of two convex functions (dc) algorithm. The best relay is selected based on the comparisons of power allocated to relay nodes. Such schemes would be typically applicable to a network where allocation of orthogonal channels to sensor nodes will not be feasible such as marine WSNs, border sensor networks etc. Numerical and simulation results are also provided. Comprehensive analysis and extensive simulations show our scheme to be highly effective and flexible in balancing the cost and quality of service (QoS) performance.**

I. Introduction

For a large WSN, sensors are often hierarchically organized into clusters. Clustering is a technique which can reduce energy consumption in a network, as well as provide scalability. Approaches in the literature to maximize network lifetime include clustering and it is one of the most important approaches for energy saving by keeping only a portion of nodes active in each cluster.

A proper choice of relaying terminals can substantially improve the efficiency of the cooperative network. An intuitive relay selection scheme has been shown in [1], where three relay selection schemes are derived for uniformly distributed wireless sensor networks: 1) optimal selection where the relays that maximize the signal-to-noise ratio (SNR) at the destination are selected, 2) geometry-based, which is based on selecting the closest nodes to the source, and 3) random selection in which the nodes are selected randomly from a certain neighborhood of the source, where they assume that all relays operate in the amplify-and-forward mode and transmit with equal average powers. In [2], authors have generalized the idea of multiple relay selection scheme which allocates the total relay power optimally to best relays selected to maximize signal-to-noise ratio for two hop cooperative communication between source to relay and relay to destination. A relay selection scheme based on the channel gains of the source-relay and relay-destination links is discussed in [3]. The work in [4] showed a relay selection scheme combined with feedback and adaptive forwarding in cooperative communication systems. The work in [5] proposed a class of opportunistic power allocation schemes suitable for amplify and forward WSNs with sensor observations being conveyed over a set of orthogonal channels.

A multi-relay nodes selection strategy, taking both instantaneous channel state information and remaining energy as weighted metrics has been shown in [6] for a wireless cooperative relay network. In [7], authors have generalized the optimal power allocation and relay position strategies based on the tight outage probability approximation, for cooperative multicast to minimize the average outage probability. The work in [8] showed a power-balanced approach that aims at directly optimizing coverage time by accounting the impacts of both intra and inter-cluster traffic. They considered both deterministic and stochastic topology models. In the deterministic case, sensors and CHs are arbitrarily placed, but their locations are known. In stochastic case, where sensor locations are not available beforehand, they have considered a sensing region with uniformly distributed sensor nodes and the traffic of a CH is delivered to the sink either directly or via other CHs. An intuitive impact of intra and inter-cluster traffic was proposed where ongoing traffic controlled by CHs. The whole system reliability depends on CHs energy consumption hence it is not an optimal power scheme. In [9], authors have developed a power-efficient relay selecting scheme which is based on node location information with overall SER (Symbol Error Rate) constraint and maximum power limit of a node. In practical randoms deployed network node location information will not be known.

The work in [10] showed an interference model, under this model, two edges are said to interfere if either endpoint node of one edge is within the interference range of an endpoint node of the other edge. The authors in [11] proposed an efficient relay selection protocol based on geographical information for cluster-based cooperative WSNs. They analyze the best position of the relay for CHs which minimizes the symbol error probability at destination. They have assumed that in both phases all sensors transmit signals through orthogonal channels by using TDMA, FDMA or CDMA scheme in order to avoid impact of intra and inter-cluster interference. The same work has been analyzed in [12] where a joint optimization of power allocation and relay selection scheme has been developed.

Most of the current literature on relay selection and power allocation schemes ignore the impact of intra and inter-cluster interference effect for the cluster-based cooperative WSNs. Often, the only considered factor that is sensor observations being conveyed over a set of orthogonal channels that manifests itself for the increment of end-to-end delay which is one of the important parameter of QoS for any network. Such a simplistic approach to model the cluster-based cooperative WSNs may not always be appropriate due to the following two reasons: 1) The practical model consists of randomly deployed sensor nodes and it may not possible to allocate orthogonal channels to sensor nodes and 2) This model does not offer any analytical description of intra and inter-cluster interference effect for the cluster-based cooperative WSNs on joint relay selection and power allocation scheme.

The main motivation of this work is to analyze a joint power allocation and relay selection scheme that explicitly takes into consideration the impact of intra and inter-cluster interference effect for the cluster-based cooperative WSNs.

Such schemes would be typically applicable to a network where allocation of orthogonal channels to sensor nodes will not be feasible such as marine WSNs, border sensor networks etc.

II. System Model

Cluster-based WSNs is organized into clusters. Consider a clustered-based sensor network whose nodes are randomly deployed over a given geographical area of interest as shown in Fig.1. Each cluster is composed of a set of equal number of sensing nodes and one CH is responsible for monitoring a given geographical area. We adopt a heterogeneous model where nodes are deployed randomly and consist of two types of nodes, sensing nodes and CHs. Sensing nodes are normal sensors whose responsibility is to sense the surrounding environment and then transmit the collected data directly to CHs. We assume that CHs nodes are less energy-constrained than sensing nodes. Consequently, two main roles for CHs can be defined. The first is gathering information from their cluster members. The second is relaying their data toward the fusion center through multi-hop communication with the help of an optimum relay.

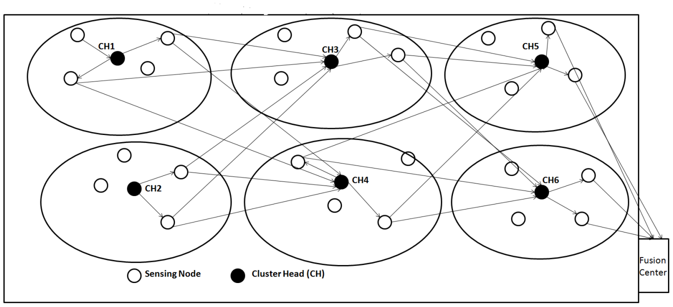

Fig. 1. Clustered-Based Cooperative WSN

A. *Transmission Model*

A node is in active condition represents the ability to receive as well as to transmit the signal, while any node in sleep condition will only able to receive the signal. A cluster is in active state represents CH and all nodes present in the cluster are in active condition. Hence in order to reduce energy consumption sensor node can be turn into sleep condition when not transmitting.

Let in time slot T_1 cluster consisting of CH_1 and CH_2 is in active state. In another time slot of T_2 cluster consisting of CH_3 and CH_4 is in active state similarly in another time slot of T_3 cluster consisting of CH_5 and CH_6 is in active state and so on. Hence in each time slot there are two clusters in active state.

Cluster to cluster transmission consists of single hop communication scheme which forms the simplified cooperative relay network as shown in Fig.2, which consists of sources CH_1 and CH_2 having destination CH_3 and CH_4 with 4 available relays $(R_i, i = 1, 2, 3, 4)$. Each node of a cluster is having estimated position of CHs of their neighbor clusters which helps to make cooperative communication from relay nodes to destination. With the relay selection mechanism, the source cooperates with active relays to transmit its data to the destination. We consider a cooperative system with half-duplex terminals each of which is equipped with a single pair of transmit and receive antennas. Let $h_{i,j}$ denotes the fading coefficient of the channel from node i to node j. We assume the magnitude $|h_{i,j}|$ follows a Rayleigh distribution.

The cooperative diversity transmission under consideration is composed of following phases as follows. During half of transmitted symbol duration nodes will sense the surrounding environment and then transmit the collected data directly to CHs. During another half of transmitted symbol duration half of the nodes will turn off to sleep condition. In the first phase, the source broadcasts its symbol with transmission power P_s to relay. In the second phase, with a simple amplify and forward(AF) strategy, the active relay will broadcast its symbol to the destination.

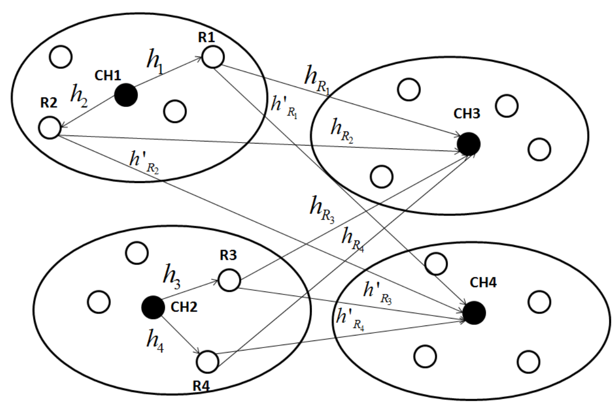

Fig. 2. Simplified Cooperative Relay Network

III. Channel Estimation Model

We consider a pilot-symbol-assisted (PSA) channel estimation scheme. Also fading channels are sufficiently slow varying such that channel coefficients keep constant for duration T by which two neighbor clusters are in active state. Hence it is a quasi-static channel and we will estimate the channels after every duration T with transmitted symbol duration $T/16$.

A. *Channel Estimation From Source to Relay Model*

Assume that a pilot symbol a transmitted from source (CHs) CH_1 and CH_2 to corresponding relays R_1, R_2, R_3 and R_4 to estimate channel h_1, h_2, h_3 and h_4 as shown in Fig.2.

Assume h_1 and h_2 are circularly symmetric complex Gaussian random variables with zero mean and known variances σ_i for $i = 1, 2$ having receive spatial constant correlation coefficients $\rho 1$. similarly we assume h_3 and h_4 are circularly symmetric complex Gaussian random variables with zero mean and known variances σ_i for $i = 3, 4$ having receive spatial constant correlation coefficients $\rho 2$. We assumed channel coefficient h_1 and h_2 are independent to channel coefficient h_3 and h_4.

From [13], we have minimum mean-square error (MMSE) estimators which have the attractive feature that in the Gaussian case they are linear and thus easy to implement. MMSE estimate of h_1 and error covariance matrix is given by

$$\hat{h}_1 = m_{h_1} + K_{h_1 Y_{R_1}} K^{-1}_{Y_{R_1} Y_{R_1}} (Y_{R_1} - m_{Y_{R_1}}) \quad (1)$$

$$K_{E_1} = K_{h_1 h_1} - K_{h_1 Y_{R_1}} K^{-1}_{Y_{R_1} Y_{R_1}} K_{Y_{R_1} h_1} \quad (2)$$

Where m_{h_1} is mean of h_1, $K_{h_1 Y_{R_1}} = E\{h_1 Y^H_{R_1}\}$, $K_{h_1 h_1} = E\{h_1 h^H_1\}$, $K_{Y_{R_1} h_1} = E\{Y_{R_1} h^H_1\}$, $K_{Y_{R_1} Y_{R_1}} = E\{Y_{R_1} Y^H_{R_1}\}$, $m_{Y_{R_1}}$ is mean of Y_{R_1}.

Where Y_{R_1} is received signal at relay R_1 and is given by

$$Y_{R_1} = a\sqrt{P_s} h_1 + n_{R_1} \quad (3)$$

Where P_s = source transmit power and $n_{R_1} \sim \mathcal{CN}(0, \sigma^2_{n_1})$ is circularly symmetric complex Gaussian noise with known variance.

We can write estimate of channel h_1 from equations (1) and (3)

$$\hat{h}_1 = (a\sqrt{P_s}\sigma^2_1)(P_s a^2 \sigma^2_1 + \sigma^2_{n_1})^{-1} Y_{R_1} \quad (4)$$

Similarly we can estimate channel h_2, h_3 and h_4 from the received signal Y_{R_2}, Y_{R_3} and Y_{R_4} at relay R_2, R_3 and R_4. Where

$$Y_{R_i} = a\sqrt{P_s} h_i + n_{R_i}, i = 2, 3, 4. \quad (5)$$

We assumed additive noise term n_{R_1}, n_{R_i} for $i = 2, 3, 4$ are independent with distribution $\sim \mathcal{CN}(0, \sigma^2_{n_i})$ random variables with known variances.

Hence from equations (1), (3) and (5) we can write

$$\hat{\mathbf{H}}_\mathbf{s} = (a\sqrt{P_s}\sigma^2_i)(P_s a^2 \sigma^2_i + \sigma^2_{n_i})^{-1} \mathbf{Y_R}, i = 1, 2, 3, 4 \quad (6)$$

Where

$$\hat{\mathbf{H}}_\mathbf{s} = \begin{pmatrix} \hat{h}_1 \\ \hat{h}_2 \\ \hat{h}_3 \\ \hat{h}_4 \end{pmatrix}, \mathbf{Y_R} = \begin{pmatrix} Y_{R_1} \\ Y_{R_2} \\ Y_{R_3} \\ Y_{R_4} \end{pmatrix} \quad (7)$$

IV. Analysis of Signal to Interference Noise Ratio

Let x is the transmitted symbol from source CH_1 and CH_2 to corresponding relays R_1, R_2, R_3 and R_4.

The received signal at relays R_1, R_2, R_3 and R_4 is given by

$$Y_{R_i} = x\sqrt{P_s} h_i + n'_{R_i}, i = 1, 2, 3, 4. \quad (8)$$

Where in equation (8) we assumed additive noise term n'_{R_i} for $i = 1, 2, 3, 4$ be independent $\sim \mathcal{CN}(0, \sigma^2_{n_i})$ random variables with known variances.

At destination CH_3 i.e D the received signal due to relays R_1, R_2, R_3 and R_4 is given by

$$Y_{D_i} = G_i Y_{R_i} h_{R_i} + n'_{D_i}, i = 1, 2, 3, 4. \quad (9)$$

Where in equation (9) we assumed additive noise term n'_{D_i} for $i = 1, 2, 3, 4$ be i.i.d $\sim \mathcal{CN}(0, \sigma^2)$ random variables with known variances. Let h_{R_1}, h_{R_2}, h_{R_3} and h_{R_4} are circularly symmetric complex Gaussian random variables with zero mean and known variance σ_R having transmit correlation coefficients ρ. We consider that channel h_i and h_{R_i} are independent for $i = 1, 2, 3, 4$. G_1, G_2, G_3 and G_4 is amplifying gain of relays R_1, R_2, R_3 and R_4 which we can compute from [14] for unit power of transmitted symbol and it is given by

$$G_i = \sqrt{P_{R_i}}\{P_s E\{\hat{h}_i \hat{h}^H_i\} + \sigma^2_{n_i}\}^{-1/2}, i = 1, 2, 3, 4. \quad (10)$$

From equations (6) and (10) we can write

$$G^2_i = P_{R_i}\{P_s E\{\hat{h}_i \hat{h}^H_i\} + \sigma^2_{n_i}\}^{-1} = P_{R_i} C_i, i = 1, 2, 3, 4. \quad (11)$$

Where

$$C_i = \frac{a^2 P_s \sigma^2_i + \sigma^2_{n_i}}{a^2 P^2_s \sigma^4_i + (a^2 P_s \sigma^2_i + \sigma^2_{n_i})\sigma^2_{n_i}}; \quad (12)$$

From equation (9) the received signal at destination D is given by

$$Y = \sum_{i=1}^{4} Y_{D_i} \quad (13)$$

From equations (13) we can write

$$Y = G_1 x\sqrt{P_s} h_1 h_{R_1} + G_2 x\sqrt{P_s} h_2 h_{R_2} + G_3 x\sqrt{P_s} h_3 h_{R_3} +$$
$$G_4 x\sqrt{P_s} h_4 h_{R_4} + G_1 h_{R_1} n'_{R_1} + G_2 h_{R_2} n'_{R_2} + G_3 h_{R_3} n'_{R_3} +$$
$$G_4 h_{R_4} n'_{R_4} + n'_{D_1} + n'_{D_2} + n'_{D_3} + n'_{D_4} \quad (14)$$

From equation (14) we can write expression of SINR and it is given by equation (15) and (16). Similarly we can write expression of SINR for k_1 and k_2 number of active relays in two clusters and it is given by equation (17) on top of next page.

$$SINR = \frac{P_s G^2_1 \sigma^2_1 \sigma^2_R}{\sum_{i=2}^{4} P_s G^2_i \sigma^2_i \sigma^2_R + \sum_{i=1}^{4} G^2_i \sigma^2_{n_i} \sigma^2_R + \lambda} \quad (15)$$

Where

$$\lambda = P_s \rho \sigma^2_R \rho_2 \sum_{i=3, i\neq j}^{4} G_i G_j \sigma_i \sigma_j + 4\sigma^2, G^2_i = P_{R_i} C_i \quad i = 1, 2, 3, 4. \quad (16)$$

$$SINR = \frac{P_s G_1^2 \sigma_1^2 \sigma_R^2}{\sum_{i=2}^{k_1+k_2} P_s G_i^2 \sigma_R^2 \sigma_i^2 + \sum_{i=1}^{k_1+k_2} G_i^2 \sigma_{n_i}^2 \sigma_R^2 + P_s \rho \sigma_R^2 \rho_1 \sum_{i=2, i\neq j}^{k_1} G_i G_j \sigma_i \sigma_j + P_s \rho \sigma_R^2 \rho_2 \sum_{i=k_1+1, i\neq j}^{k_2} G_i G_j \sigma_i \sigma_j + (k_1+k_2)\sigma^2}$$

k_1, k_2 = number of active relay in two clusters

(17)

$$G_i^2 = P_{R_i} C_i \quad i = 1, 2, 3, 4, ...(k_1+k_2). \tag{18}$$

V. Optimization of Signal to Interference Noise Ratio and Power Allocation algorithm

In many previous works, the optimization problem was directly, or indirectly, related to SNR [1], [2]. However in many practical settings it is important to optimize SINR with constraint of relay power.

We consider SINR related optimization scheme where we allocate the optimal power to relay nodes that maximize the SINR. This leads to the following optimization problem

$$\underset{\{P_{R_i}\}_{i=1}^{k_1+k_2}}{\text{maximize}} \quad SINR(\{P_{R_i}\}_{i=1}^{k_1+k_2})$$
$$\text{subject to} \quad \sum_{i=1}^{k_1+k_2} P_{R_i} \leq P_T$$

This optimization problem is transformed into one that minimizes a difference of two convex functions (a d.c. function) over a closed convex set in $\mathcal{R}^{k_1+k_2}$. The minimization is then perform using a numerical method for solving the problem of minimizing a difference of two convex functions [15]. This algorithm combines a prismatic branch and bound technique with polyhedral outer approximation in such a way that only linear programming problems have to be solved.

We now demonstrate the d.c nature of the above optimization problem. Considering for ease of presentation the case $k_1 = 1$ and $k_2 = 1$.

Applying logarithms to both sides of equation (17) yields

$$\log(1/SINR) = F_1 - F_2 \tag{19}$$

Where F_1 and F_2 is given by

$$F_1 = -log\{P_s C_2 \sigma_2^2 \sigma_R^2 P_{R_2} + C_1 \sigma_{n_1}^2 P_{R_1} \sigma_R^2 + C_2 \sigma_{n_2}^2 P_{R_2} \sigma_R^2 + 2\sigma^2\} \tag{20}$$

$$F_2 = -log\{P_s C_1 \sigma_1^2 \sigma_R^2 P_{R_1}\} \tag{21}$$

From equation (21) we have

$$\frac{d^2 F_2}{dP_{R_1}^2} \geq 0 \tag{22}$$

From [16], we can say that F_2 is a convex function.

From equation (20) we can write

$$F_1 = -log\{(\beta + t_2)P_{R_2} + t_1 P_{R_1} + 2\sigma^2\} \tag{23}$$

Where
$P_s C_2 \sigma_2^2 \sigma_R^2 = \beta$, $C_1 \sigma_{n_1}^2 \sigma_R^2 = t_1$, $C_2 \sigma_{n_2}^2 \sigma_R^2 = t_2$
From equation (23) we can write

$$\frac{\partial^2 F_1}{\partial P_{R_1}^2} = \frac{t_1^2}{L^2} \tag{24}$$

Where $L = (\beta + t_2)P_{R_2} + t_1 P_{R_1} + 2\sigma^2$

Similarly we can write

$$\frac{\partial^2 F_1}{\partial P_{R_1} \partial P_{R_2}} = \frac{t_1(\beta + t_2)}{L^2} \tag{25}$$

$$\frac{\partial^2 F_1}{\partial P_{R_2}^2} = \frac{(\beta + t_2)^2}{L^2} \tag{26}$$

From equations (24), (25) and (26) we can write Hessian matrix and it is given by

$$\bigtriangledown^2 \mathbf{F_1} = \begin{pmatrix} \frac{t_1^2}{L^2} & \frac{t_1(\beta+t_2)}{L^2} \\ \frac{t_1(\beta+t_2)}{L^2} & \frac{(\beta+t_2)^2}{L^2} \end{pmatrix} \tag{27}$$

From equation (27) we have $\bigtriangledown^2 \mathbf{F_1} = \mathbf{0}$ hence from [16] we can define F_1 is a convex function.

F_1 and F_2 in equation (19) are convex functions. Hence equation (19) is in the form of difference of convex functions which can be solved by using d.c function based global optimization methods.

VI. Simulation Results

In this section, simulation results are presented. Two power allocation schemes compared with the proposed scheme are equal power allocation scheme [11] and the scheme in [3]. Equal power allocation scheme allocates total relay power equally among the relays. In [3], power is allocated based on corresponding channel gain of relay networks.

For our simulation we consider the parameters $\sigma_1 = 1, \sigma_2 = 1.5, \sigma_3 = 2, \sigma_4 = 2.5, \sigma_R = 3, \sigma_{n_1} = .5, \sigma_{n_2} = .6, \sigma_{n_3} = .7, \sigma_{n_4} = .8, \sigma = .9, \rho_1 = .5, \rho_2 = .7, \rho = .4$, with unit source power and pilot symbol of unit amplitude.

From the columns P_{R_1}, P_{R_2}, P_{R_3} and P_{R_4} of TABLE I, we can determine the corresponding allocated power to each relay and from the column P_T we can find the total power allocated to all relays and then the corresponding selection metric for each relay given in the column SINR of TABLE I. According to the proposed selection criteria in section (V), maximum value of selection metric SINR is 0.6651 which corresponds to R_3 is the best relay for cluster 2 and R_1 is the best relay for cluster 1.

Fig.3 illustrates the performance of SINR with number of active relay nodes. From Fig.3 we can see that with increasing number of active relay nodes, SINR can not be neglected. We have also noticed that there is a negative impact of of channel correlation coefficient on the SINR performance parameter.

Fig.4 illustrates the performance of our optimization scheme with respect to SINR for different values of noise standard deviation and and shows the improvement of the SINR performance parameter for the optimal relay.

In Fig. 5, the performance of direct transmission from the source to the destination is provided as a benchmark for a non-cooperation scheme. In Fig.5, we compare our proposed scheme to equal power allocation scheme [11] and we also compare the performance with a non-cooperation scheme. Thus, we have demonstrated that in our scheme of joint optimization of SINR and power allocation, nodes in wireless sensor networks can efficiently perform relay selection to improve the SINR performance at the destination. In addition, we also compare the performance with a possible power allocation scheme where power is allocated based on corresponding channel gain of relay network [3]. A good performance gain is achieved by our proposed scheme.

TABLE I
ALLOCATED RELAYS POWER AND CORRESPONDING SINR WITH
$1 \le P_{R_1} \le 3, 1 \le P_{R_2} \le 3, 1 \le P_{R_3} \le 3, 1 \le P_{R_4} \le 3$

Relay Selected	Power Allocated to Relays				Total Power	Corresponding SINR
Relay #	P_{R1}	P_{R2}	P_{R3}	P_{R4}	P_T	SINR
R_1	2.895	.999	1.199	.999	6.092	0.5687
R_2	1.001	2.901	3.005	1.001	7.908	0.4038
R_3	1.104	1	2.896	1	6	0.6651
R_4	1.201	1.001	1.001	2.905	6.108	0.6551

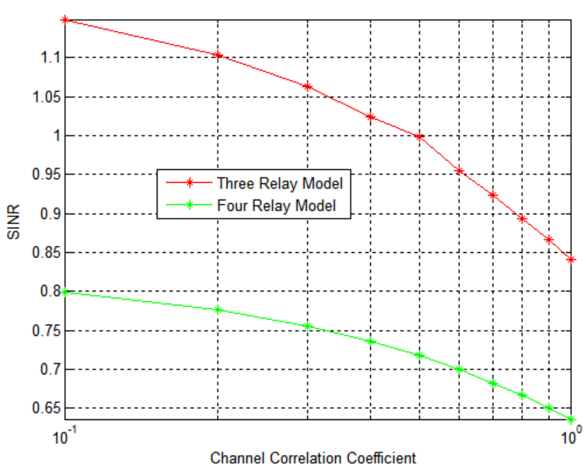

Fig. 3. Performance Analysis of SINR With Noise Standard Deviation Sigma

VII. CONCLUSION

In the present work for clustered-based WSNs in presence of interference we have provided a scheme for joint optimization of SINR and power allocation. The proposed scheme has shown a performance improvement over previous schemes. From our results we observe that there is noticeable gain in performance for the best relay. We have also noticed that

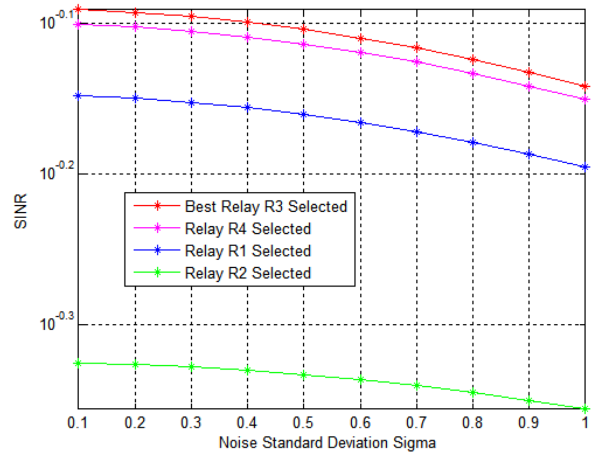

Fig. 4. Performance Gain with Best Relay Selection

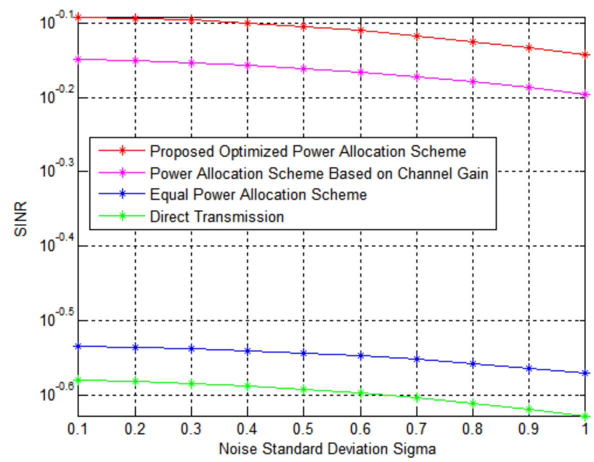

Fig. 5. Comparison of Proposed Power Allocation Scheme With Various Scheme.

there is negative impact on performance parameter of channel correlation coefficient.

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