International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Energy Efficient Cooperative Relay Network Design

Azhar Hussain Khan[1], G. Prapulla[2]

[1]M.Tech-Digital Communication, Departmentof Electronics and Communication Engineering, BMS College of Engineering, Bangalore

[2]Associate Professor, Department of Electronics and Communication Engineering, BMS College of Engineering, Bangalore, India

Abstract: ***Relay links play an important role in the design of wireless networks. Consider a single antenna transceivers and multiple single antenna relay nodes, the path between the transceivers and relays will be subjected to different propagation delays. A simple amplify and forward relaying protocol is used in this paper reason being the simplicity. In this paper a novel performance metric PN-SNR is used to design an energy efficient cooperative relay network. For the single and multiple relay network scenario the PN-SNR maximization problem is solved and the performance is analysed. The analysis is extended to multi antenna transceivers and compared. The paper emphasizes the potential of PN-SNR in designing the energy efficient relay network.***

Keywords: Relay network, power normalized SNR, efficiency, power control**.**

1. Introduction

There has been a plenty of research in the wireless communication to cope with the increased bandwidth demand and to provide users wireless access anywhere anytime. Various technologies have been developed such as diversity techniques to serve the purpose. Common diversity techniques such as time, frequency, code and space have been well studied in the literature. Lately a new diversity technique known as cooperative communication with relay networks has gain popularity in the research community [1]-[4].

In cooperative communications, users relay each other's messages thereby providing multiple paths from the source to the destination leading to increased coverage. Network performance optimization are among hot topics in cooperative relay network design in recent years. There have been numerous results on the global performance optimization such as signal-to-noise-ratio (SNR) maximization, throughput maximization and error rate minimization for fixed transmit power [5], [6].The popular efficiency measures comprise of spectral efficiency and energy efficiency. These two efficiency measures have been widely studied in the literature for different network configurations, e.g., [7], [8].

The problem with these two efficiency measures is that optimization leads the system to either high power consumption or in low SNR regime. The aforementioned limitations of spectral efficiency and energy efficiency can be overcome by introducing a new efficiency metric, namely SNR-per-unit-power [9], or power normalized SNR (PN-SNR), to design energy efficient reliablerelaynetwork andto evaluate the network efficiency. For a single user network, the PN-SNR is defined as:

$$\eta = \frac{\text{SNR}}{\text{P}_{\text{total}}} \tag{1}$$

Where SNR is the end-to-end received SNR and P_{total} is the total power consumed in the network. The parameter ηrepresents the achievable received SNR per unit transmit power.

In this paper the performance of the network is evaluated with realistic channel model such as introducing the effect of fading, scattering etc. The PN-SNR is a more natural efficiency measure as it shows the performance per unit power and it does not trap the network in the low power regime and provide better power control mechanism.

2. System Model and Problem Formulation

Consider a general distributed network with one transmitter, one receiver and R relays, as depicted in Figure1. Each relay has a single antenna which can be used for both transmission and reception. The channel from the transmitter to the ith relay is represented as f_i and the channel from the *ith* relay to the receiver asg_i.It is assume that each relay knows its own channels and the receiver knows all channels. The channel state information at the receiver end can be obtained via channel estimation [8],[11]. The ith relay can obtain f_i by training and,$g_i$by feedback. Let $\mathbf{f}= [f_1, f_2. . . f_R]^T$ and $\mathbf{g} = [g_1, g_2. . . g_R]^T$, which are the transmitter-relay and relay-receiver channel vectors. Consider a two-hop amplify-and-forward (AF) relaying protocol, where the relays adjust the amplitudes and the phases of their received signals. In the second hop, the *ith* relay multiplies its received signal by a complex weight w_i to adjust the phase and magnitude of thereceived signal, and transmits the adjusted signal towards the receiver. The signals received at the relays can be represented as

$$x = \sqrt{P_o}\boldsymbol{f}s + z \tag{2}$$

where x is the Rx1 complex vector of the signals received by the relays and z is the Rx1 complex vector of the relay noises. The distribution of z depends on the channel model and differs for AWGN, Rayleigh and Rician models. The Rx1 complex vector t of the transmitted signals of all relays can then be expressed as

$$\mathbf{t} = \mathbf{w} \bullet \mathbf{x} \tag{3}$$

where$\mathbf{w}$= $[w_1, w_2 \ldots\ldots w_R]$ is referred as the beamforming vector. Consider the transmitted signal of the *i*th relay as t_i,the power consumed on *i*th relay can be calculated as

$$\text{P}_\text{i}=\text{E}\,\{|t_i|^2\} =(1 + P_o|f_i|^2)|w_i|^2 \tag{4}$$

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

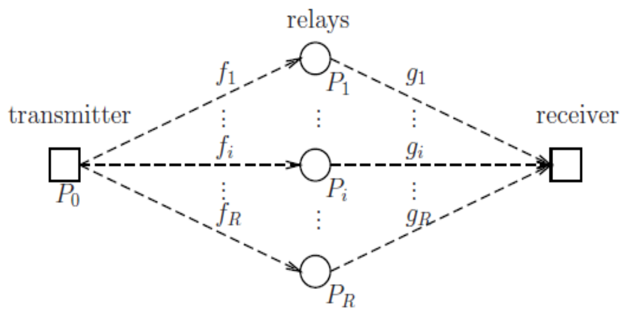

Figure 1: Two hop multi relay network

With simple calculations the end-to-end SNR can be expressed as

$$SNR = \frac{P_o \left(w^T h\right)^2}{(1+\|w\bullet g\|^2)} \tag{5}$$

The total power consumed in the whole network is

$$P_T = P_o + P_o\|w\bullet a\|^2 \tag{6}$$

According to the definition, PN-SNR of the relay network is

$$\eta = \frac{SNR}{P_T} = \frac{P_o\,(w^T h)^2}{(1+\|w\bullet g\|^2)(P_o + P_o\|w\bullet a\|^2)} \tag{7}$$

Let $w_i = \alpha_i.e^{j\theta i}$,$\alpha = [\alpha_1 \alpha_2 \dots .\alpha_R]^T$ and $\theta = [\theta_1 \theta_2 \dots .\theta_R]^T$. With straight forward calculations it can be shown that

$$\eta = \frac{\left(\alpha^T b\right)^2}{(1+\|\alpha\bullet d\|^2)(1+\|\alpha\bullet a\|^2)} \tag{8}$$

where $b = [|f_1 g_1| \dots \dots |f_R g_R|], d = [|g_1| \dots \dots . . |g_R|]$

In this paper, Pois kept constant. The design problem is to find the relay power control vector α such that the PN-SNR in (8) is maximized.

3. Single-Relay Network Case

In single-relay networks, the relay power control vector and channel vectors reduce to scalars, i.e., $\boldsymbol{\alpha}$ reduces to α,$\boldsymbol{f}$ reduces to$f$, and $\boldsymbol{g}$ reduces to$g$. The power constraint on the relay was denoted as$P_{R,lim}$, and the actual transmit power of the relay was denoted as$P$. Thus,P $\leq P_{R,lim}$, from(7), the end-to-end received SNR can be expressed as

$$SNR = \frac{|fg|^2 P P_0}{1+|f|^2 P_0 + |g|^2 P} \approx \frac{|fg|^2 P P_0}{|f|^2 P_0 + |g|^2 P} \tag{9}$$

In the second equality in (9), an approximation has been used which prevails when the channel gains are high. The corresponding PN-SNR of the network is thus

$$\eta = \frac{|fg|^2 P P_0}{(1+|f|^2 P_0 + |g|^2 P)(P+P_0)} \tag{10}$$

The solution to PN-SNR maximization problem is derived as follows. The ideal case that the relay power is unlimited, i.e., $P_{R,lim} = \infty$ is considered first and then the practical case of finite power $P_{R,lim}$.By using (10), PN-SNR maximization problem for single relay network is shown as

$$\max_{P>0} \frac{|fg|^2 P P_0}{(1+|f|^2 P_0 + |g|^2 P)(P+P_0)} \tag{11}$$

By differentiating the objective function in (11) with respect to P and equating it to zero, the optimal relay power, denoted as P_{opt}, is obtained as

$$P_{opt} = \frac{\sqrt{P_0(1+|f|^2 P_0)}}{|g|} \tag{12}$$

When the transmitter power is high ($P0 \gg 1$), the solution can in (12) can be approximated as

$$P_{opt} = \frac{|f|}{|g|} P_0 \tag{13}$$

And for the practical case of $P_{R,lim}$ being finite, i.e., $P_{R,lim} < \infty$, the PN-SNR maximizing solution is extended from (13) as:

$$P_{opt} \approx P_{approx} = \min\left(\frac{|f|}{|g|} P_0, P_{R,lim}\right) \tag{14}$$

With the solution so obtained the simulation is carried out for single relay network, and the average PN-SNR has been plotted for the three schemes.

4. MultiRelay Case with Sum Power Constraint

Extending the analysis of single-relay model to multi-relay model, the PN-SNR maximization is carried out for multi relay network. A total sum power constraint is imposed on the relays such that the total power consumed by all the relays, denoted as P, is no larger than $P_{R,lim}$ .i.e.,

$$\mathrm{P} = \sum_{i=1}^{R} P_i \leq P_{R,lim} \tag{15}$$

This sum power constraint model is very popular and is widely used .The transmitter power is assumed to be fixed as P_0.From (4) and (8), the PN-SNR maximization problem is:

$$\max_{\alpha>0} \frac{(\alpha^T b)^2}{(1+\|\alpha\bullet d\|^2)(1+\|\alpha\bullet a\|^2)} \tag{16}$$

s.t $\sum_{i=1}^{R}(1+P_0|f_i|^2)|\alpha_i|^2 \leq P_{R,lim}$

This is a non-convex optimization problem.Newton's method for maximization is been used for optimizing the PN-SNR.

5. Multi Relay Case with Separate Power Constraint

In this section the PN-SNR maximization problem is investigated with separate relay power constraint where the ith relay has its own power constraint denoted as $P_{i,lim}$.From (4) and (8) the PN-SNR maximization problem can be described as

$$\max_{\alpha>0} \frac{(\alpha^T b)^2}{(1+\|\alpha\bullet d\|^2)(1+\|\alpha\bullet a\|^2)} \tag{17}$$

s.t $0 \leq \alpha_i \leq \sqrt{\frac{P_{i,lim}}{1+P_o|f_i|^2}}$, $for\ i = 1, \dots .R$

where $a \triangleq \left[\sqrt{\frac{1}{P_0} + |f_1|^2} \dots \dots \sqrt{\frac{1}{P_0} + |f_R|^2}\right]$

This is again a non-convex optimization problem in which finding a globally optimal solution requires extensive computation. It requires to use a blend of search algorithm and optimization algorithms such as SQP and gradient ascent. To reduce the complexity a suboptimal solution is obtained by neglecting the power constraints which leads to the equivalent of using newton's method of optimization.

6. Single-Relay Network with MIMO

The system model considered in section 2consist of single antenna transceivers. To further show the potential of PN-

SNR in designing energy efficient relay networks the general single relay network is evaluated with multiple antennas at the transmitters and receivers side i.e.; employing MIMO.The system model so obtained is shown in the Figure2.The analysis and maximization problem is similar to the previous cases except the change that the channel vectors **f** and **g** now becomes the channel matrices F and G respectively. So the PN-SNRmaximization problem now becomes as

$$\max_{P>0} \frac{|FG|^2 P P_0}{(1+|F|^2 P_0+|G|^2 P)(P+P_0)} \qquad (18)$$

7. Simulation Results

In this section the simulated performance of the proposed PN-SNR maximization scheme is presented for single andmulti-relayscenario. Also the performance is compared with the fixed relay power scheme and SNR-maximizing scheme.

7.1 Single Relay Networks

In this subsection the simulation result for single relay network case is presented. The average PN-SNR is plotted for the proposed PN-SNR scheme represented as "Proposed", the SNR-maximizing scheme denoted as "SNR-max" and the fixed relay power scheme denoted as "Fixed Power".

Two cases are considered for relay power viz; P(lim)=infinite and P(lim)=P_o. Figure3shows the average PN-SNR for the three mentioned scheme.It is evident that the proposed PN-SNR scheme outperforms the other two techniques but there is a merging of the fixed relay power and proposed method graph for P(lim)=P_o case .It is so because it is assumed that the average relay power consumption in both the scheme is maintained same. Over the long course of time when there is sufficient change in channel state they would differ.

Figure 4 shows the average received SNR for the three schemes. The proposed scheme has comparable performance in average SNR with the fixed relay power scheme but it is inferior to the SNR-maximizing scheme. The average SNR increases for all the three schemes as the transmitter power increase as shown in Figure4. Figure 5 shows the plot of energy efficiency in bits per joule of the three schemes. It is observed that the proposed design achieves the best energy efficiency. However, the energy efficiency for all three schemes is decreasing as P_o increases.

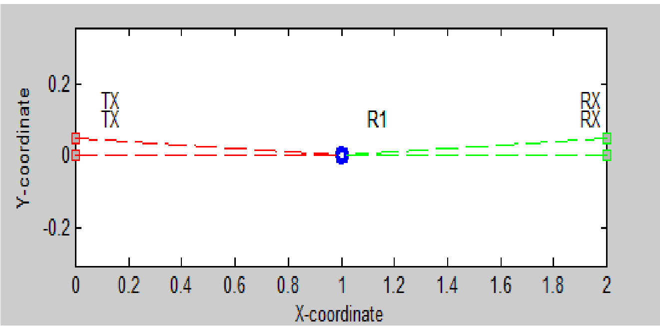

Figure 2:two hop transmission network with two antennas at the transmitter and receiver

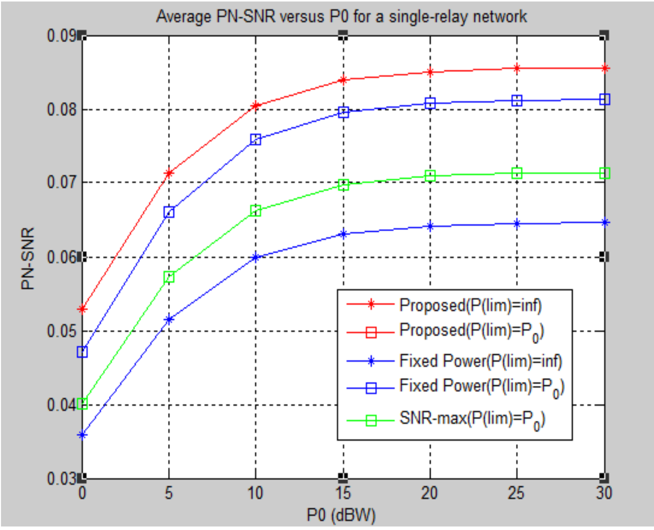

Figure 3: Average PN-SNR versus transmitter power for single relay network

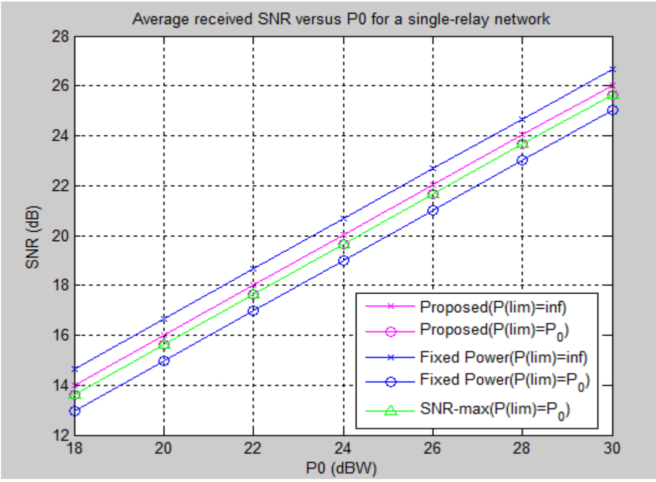

Figure 4: Average received SNR for single relay network

7.2Multi Relay Networks

In this subsection the simulation result for multi relay network is presented. The results are shown for two relays. Figure6 shows the average PN-SNR plotted for all the three schemes with a sum relay power constraint. In the fixed relay power scheme, the sum transmit power of the relays is fixed for each transmission regardless of the channel quality.

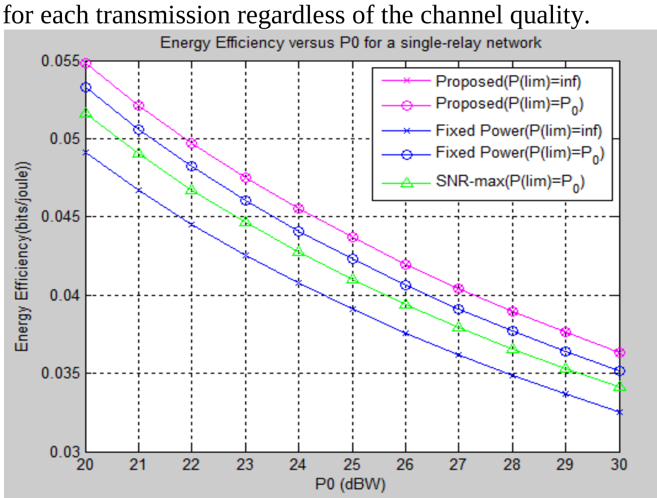

Figure 5: Energyefficiency for single relay network

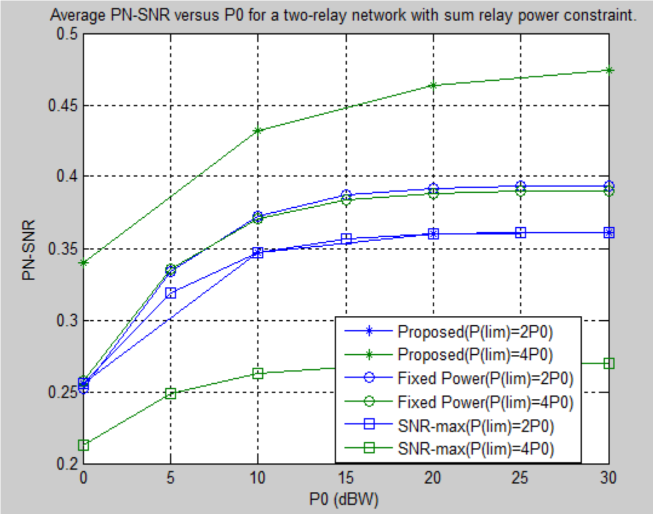

Figure6: Average PN-SNR for two relay network with sum power constraint

In the SNR-maximizing scheme, the relays always use the maximum sum power $P_{R,lim}$ to achieve the maximum SNR. Figure 6, shows the simulation result of a two-relay network with the sum power constraints $P_{R,lim} = 2P_0$ and $P_{R,lim} = 4P_0$ for the three schemes. In the PN-SNR maximizing scheme, the average PN-SNR decreases as $P_{R,lim}$ changes from $2P_0$ to $4P_0$.In the fixed relay power scheme, the average PN-SNR slightly decrease as $P_{R,lim}$ increases, In the SNR-maximizing scheme, the average PN-SNR sharply decreases as $P_{R,lim}$ increases. Among the three schemes, the proposed scheme always achieve the highest PN-SNR.

Figure 7 shows the average PN-SNR for two relay network with each relay having its own power constraint. The plot shows that proposed scheme has better PN-SNR than fixed power scheme and SNR-max scheme.For the SNR-maximizing scheme,objective is to maximize the end-to-end received SNR. For the fixed relay power scheme, all relays transmit with their maximum power and no channel information is needed. Both schemes have the same power constraint for each relay as the proposed method. But the proposed method may reduce the relay power for better efficiency, thus actually consumes less power.

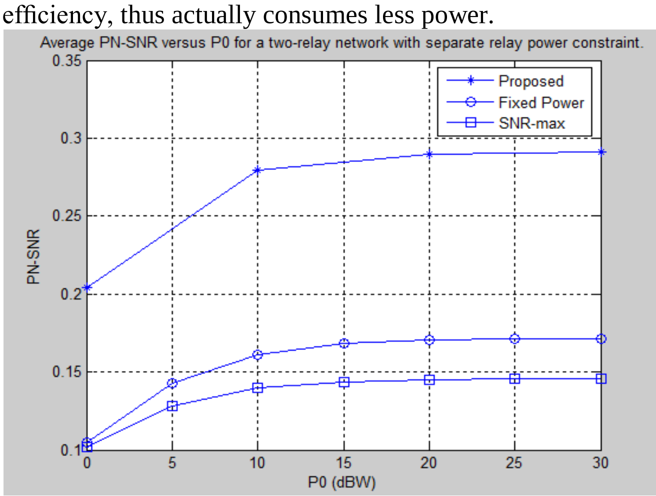

Figure 7: Average PN-SNR for two relay network with separate power constraint

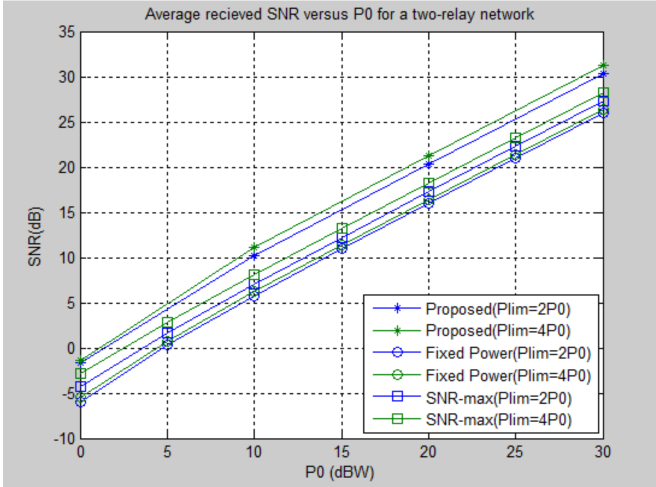

Figure 8: Average received SNR for two relay network with sum power constraint

The Figure 8 shows the average received SNR for the two relay network. From the plot it is evident that the proposed PN-SNR scheme has better received SNR than other two schemes since proposed method is based on the channel condition. The average SNR increases for all the three schemes as the transmitter power increase as shown in Fig8.

7.3 Single Relay Networkwith MIMO

Figure 9 compares the average PN-SNR for a single relay network with single and multiple antenna transceivers. In the case of multiple antennas (two in the simulation) at the transmitter and receiver the PN-SNR is further improved with the same transmitter power as compared with the single antenna model. At 10 dBW the PN-SNR is improved by 40% in MIMO model. So it is proved that PN-SNR is worth being used as a metric in designing energy efficient networks.

Figure 10 shows the energy efficiency for single relay network with SISO and MIMO configuration. The energy efficiency decreases rapidly for SISO and gradually for MIMO model as the transmitter power increases. Efficiency is better in the MIMO model and it maintains it even if the transmitter power changes by nominal amount. Recall that energy efficiency is calculated in bits/joule.

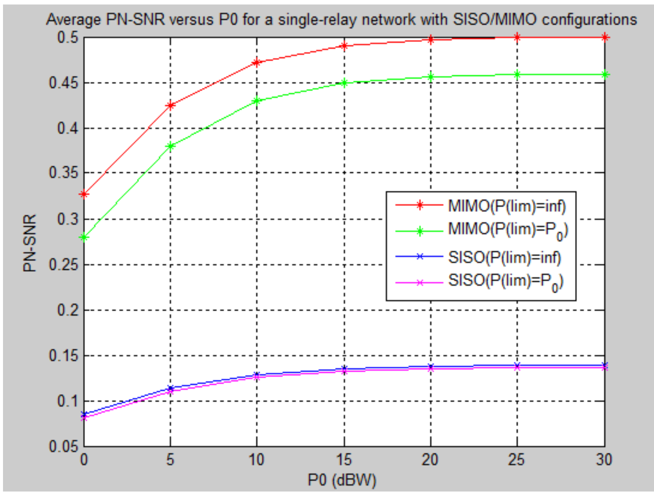

Figure 9: Comparison of Average PN-SNR for single relay network with SISO/MIMO configurations.

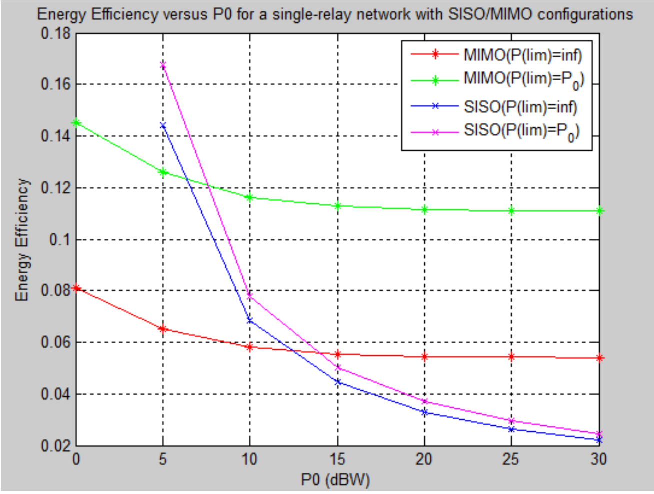

Figure 10: Comparison of energy efficiency for single relay network with SISO/MIMO configurations

8. Conclusion

In this paper a new performance metric, namely power normalized SNR is used to design energy efficient cooperative relay networks and moreover a relay power control scheme is proposed which maximizes this metric. For high PN-SNR the relays adjust their powers based on the channel quality and hence better use of the most important resource that is energy. This paper deals with sum and separate relay power controls and justifies the use of PN-SNR as an efficiency measure in the energy efficient relay network design. The relay network is analysed with multiple antenna transceivers as well and our proposed scheme is proven to give better result in every possible scenario. This work can be extended to multiple antennas relays and that is the direction we are looking forward to next for future work.

References

[1] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity part I. System description," IEEE Trans. Commun., vol. 51, pp. 1927–1938, Nov. 2003.
[2] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity Part II. Implementation aspects and perfromance analysis," IEEE Trans. Commun., vol. 51, pp. 1939–1948, Nov. 2003.
[3] J. Laneman, D. Tse, and G.Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," IEEE Trans. Inf. Theory, vol. 50, pp. 3062–3080, Dec. 2004.
[4] Y.-W. Hong, W.-J. Huang, F.-H. Chiu, and C.-C. J. Kuo, "Cooperative communications resource constrained wireless networks," IEEE Signal Process. Mag., vol. 24, no. 3, pp. 47–57, May 2007.
[5] P. Larsson, "Large-scale cooperative relaying network with optimal combining under aggregate relay power constraint," in Proc. 2003 FutureTelecommunications Conference, pp.160–170.
[6] S. ShahbazPanahi and M. Dong, "Achievable rate region under joint distributed beamforming and power allocation for two way relaynetworks,"IEEE Trans. Wireless Commun., vol. 11, no. 11, pp. 4026–4037, Nov. 2012.
[7] Y. Zhao, R. Adve, and T. J. Lim, "Improving amplify-and-forward relay networks: optimal power allocation versus selection," IEEE Trans.Wireless Commun., vol. 6, no. 8, pp. 3114–3123, Aug. 2007.
[8] J. M. Paredes and A. B. Gershman, "Relay network beamforming and power control using maximization of mutual information," IEEE Trans.Wireless Commun., vol. 10, no. 12, pp. 4356–4365, Dec. 2011.
[9] Yichen Hao, Yindi Jing, and Shahram ShahbazPanahi "Energy efficient network beamforming design using Power-Normalized SNR",IEEE Trans. Wireless Commun,vol. 13,no. 5,pp. 2756-2769, May. 2014.
[10] Y. Jing and H. Jafarkhani, "Network beamforming using relays with perfect channel information," IEEE Trans. Inf. Theory, vol. 55, no. 6, pp. 2499–2517, June 2009.
[11] C. J. K. Y. W. P. Hong, W. Huang, Cooperative Communications and Networking: Technologies and System Design. Springer, 2010.
[12] M. Chiang, "Nonconvex optimization in communication systems," Advances in Mechanics and Mathematics, vol. 3, D. Y. Gao and H. D. Sherali, Eds., 2006.