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ORIGINAL ARTICLE

An approach to implement PSO to optimize outage probability of coded cooperative communication with multiple relays

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Abstract Coded Cooperative Communication is a novel concept and it is the solution to utilize the benefits of MIMO (Multiple Input Multiple Output) gains on distributed scale. In this paper the outage behavior of coded cooperative communication with multiple relays is examined. The numerical expression for outage probability is derived. Nakagami-m fading statics is considered. Outage probability is observed to be function of various free and constrained parameters. An approach is presented to implement PSO and optimize the free parameters on which outage probability of coded cooperative communication with multiple relay depends. Analytical and Matlab simulation results reveal that the proposed technique outperforms Non Optimized technique and exhibit a promising performance.

1. Introduction

The basic concept of Cooperative Communication is originated by Multiple Input Multiple Output (MIMO) wireless communication system. Cellular phones and other wireless terminals are unable to accommodate multiple transmitters and receivers because of the constrain in size and other hardware limitations. Multipath fading has an adverse effect on wireless communication. This phenomenon of multiple fading becomes more evident in networks such as Wireless Sensor Networks (WSN) and Adhoc Networks. The reason is that in such type of networks the physical deployment of the mobile or immobile wireless nodes make them more susceptible to interference. In such cases it becomes mandatory to implement a mechanism, which can combat fading. MIMO because of the presence of multiple transmitters and receivers provide spatial diversity. Spatial diversity can overcome the effects of multipath fading. Though MIMO offers spatial diversity, but its implementation becomes difficult because of the hardware limitations and size constrains of the wireless nodes. Cooperative Communication comes as a savior in such situations as it helps in creating VMIMO (Virtual MIMO). It provides all the benefits of MIMO with the availability of same existing resources.

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The broadcast nature of wireless communication helps in the achievement of Cooperative Communication. Every node can hear its neighboring nodes, and can communicate with them. In cooperative scenario single nodes can share their antennas thus, creating a virtual antenna array. Laneman and Wornell laid foundation for Cooperative Communication by presenting relay channel model [1]. Repetition based Cooperative protocols such as Amplify and forward, Decode and forward were proposed. Certain limitations are associated with these protocols [2,3]. In order to overcome the short comings cooperative signaling was incorporated with channel coding and a new Cooperative Communication protocol was proposed [4,5]. This Cooperative Protocol is termed as Coded Cooperative Communication. This protocol is different from repetition based protocols. In this protocol each cooperating node instead of repeating the received bits of its partner, broadcasts its incremental redundancy. The users information is segregated into two parts. Each user transmits its own first part via an independent fading path. The cooperating partner on receiving this part, tries to decode it. If it is able to decode it, then it further broadcasts the incremental redundancy. If it is unable to decode the first frame or compute incremental redundancy, it reverts back to Non Cooperating mode [6,7]. The outage behavior of Coded Cooperative Communication has been analyzed by Hunter [12]. Multiple Relays and Rayleigh fading scenario has been considered for the analysis. In this paper, for mathematical modeling and simulation results, Nakagami-m fading statics is considered. The outage probability is evaluated. Evaluation will reveal dependence of outage probability on various parameters. Out of these parameters free and constrained parameters are segregated from one another. The behavior of free parameters will be analytically observed with the help of simulation results. An approach is presented in which PSO will be implemented to optimize free parameters on which the outage probability of Coded Cooperative communication with multiple relays depend.

The main contribution of this paper is that it optimizes outage probability of Coded Cooperative Communication with the help of a PSO (Particle Swarm Optimization).

The outline of the remainder of the paper is as follows. Section 2 explains the system model, In Section 3 the outage probability of Coded Cooperative Communication with Multiple Relays is formulated. Further the Outage Probability is Optimized using PSO. Section 4 evaluates the performance and discusses experimental results. Finally, in Section 5 paper is concluded.

2. System model

Consider a wireless scenario, in which one source node (s), one destination node (d) and multiple relay nodes ($r_1, r_2, \ldots, r_m$) are there. The model is depicted in Fig. 1. The channel statics considered are Nakagami-m fading statics.

It has been assumed that there are in total m number of relays. r_n is any intermediate relay. Each node because of hardware limitation is outfitted with one antenna transmitter and receiver. Let D be the total number of data bits, which each node transmits. These D data bits are transmitted over two successive frames with rate R_1 and R_2 and data bits D_1 and D_2 respectively. The total rate is R, the level of cooperation (α) is given as

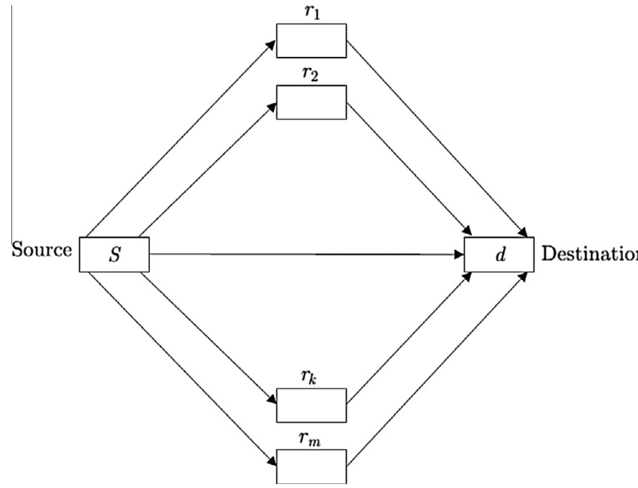

Figure 1 Model depicting source, destination and multiple relays.

$$\alpha = \frac{D_1}{D} = \frac{R}{R_1} \tag{1}$$

On reception of the first frame comprised of D_1 bits with rate R_1, the intermediate relay which is cooperating partner, tries to compute D_2 $[D_2 = D - D_1]$. If it is successful in computing D_2, it will transmit it with rate R_2 over an independent fading path. If it is not able to compute it will revert to Non Cooperating Mode and will transmit its own parity bits.

3. Performance analysis

3.1. Outage analysis

The capacity of a wireless system is characterized by instantaneous SNR and can be given by Shanons Theorem [7,8]

$$C(\gamma) = \log_2(1+\gamma) \text{ in b/s/hz.} \tag{2}$$

If the capacity drops below the certain threshold R, the channel is said to be in outage and the corresponding outage event is

$$C(\gamma) < R \tag{3}$$

Outage probability, thus evaluated will be

$$P_{out} = P_r(\gamma < 2^R - 1) = \int_0^{2^R-1} p_\gamma(\gamma)d\gamma. \tag{4}$$

$P_\gamma(\gamma)$ is the Probability Density Function of random variable.

P_{out} for Nakagami-m fading

$$P_{out} = \frac{1 - \Gamma\left(m, m\frac{(2^R-1)}{\Gamma}\right)}{\Gamma(m)}. \tag{5}$$

Γ denotes the mean value of SNR and it accounts for large scale path loss and shadowing effects $\Gamma(m)$ is the gamma distribution function and it is given as $\Gamma(m) = \int_0^\infty t^{m-1}e^{-1}dt \cdot \Gamma(m,\xi)$ is the upper incomplete gamma function and is given as $\Gamma(m,\xi) = \int_\xi^\infty t^{m-1}e^{-1}dt$ [12,14].

In Coded Cooperative Communication, the user data are transmitted over two successive frames. The transmission of the first frame is non controversial as the first frame is transmitted by the user node itself for the transmission of the second frame two cases arise.

Case 1. There is failed decoding i.e. none of the neighboring relay is able to decode successfully the frame transmitted by the source node. As discussed this is equivalent to Non Cooperative Communication i.e. both the frames will be sent by the source to destination. In the first frame from the total allocated D bits, α bits will be transmitted and in the second frame remaining bits will be transmitted. This will lead to following outage event.

$$C_{s,r_i}(\gamma_s, r_i) = \log_2(1+\gamma_{s,r_i}) < \frac{R}{\alpha}. \quad (6)$$

Case 2. There is proper decoding by some or all the relays. The successful decoding will lead to the following outage event.

$$C_{s,d}(\gamma_{s,d}) = \alpha\log_2(1+\gamma_{s,d}) + (1-\alpha)\log_2(1+\gamma_{s,d}) < R. \quad (7)$$

This event lead to

$$C_{s,r_i}(\gamma_{s,r_i}) = \log_2(1+\gamma_{s,r_i}) > \frac{R}{\alpha}. \quad (8)$$

Since the above cases are disjoint for Nakagami-m fading after simplification the equation will be:

$$C_{s,d}(\gamma_{s,d}) = \alpha\log_2(1+\gamma_{s,d}) + (1-\alpha)\log_2\left(1+\gamma_{s,d}+\sum_{i=\Omega}\gamma_{r_i,d}\right) < R. \quad (9)$$

After implementing Nakagami-m fading statics,the resulting equation will be

$$\prod_{i=1}^{M}\left[1-\Gamma(m,m)\frac{(2^{\frac{R}{\alpha}}-1)}{\Gamma_{s,r_i}}\right]\left[1-\Gamma(m,m)\frac{2^{\frac{R}{\alpha}}-1}{\Gamma_{s,r_i}}\right] \cdot\left[\int_0^{2^{\frac{R}{\alpha}}-1}\frac{m}{\Gamma(m)^2}\left(\frac{m}{s,d}\right)^m\gamma_{s,d}^{m-1}\exp\left(-m\frac{\gamma_{s,d}}{\Gamma_{s,d}}\right)\right] \cdot\left[1-\Gamma\left(-m\frac{ma}{\Gamma_{s_i,d}}\right)\right]d\gamma_{r_i,d} \quad (10)$$

3.2. Optimizing the outage probability

From the equations it can be concluded that Outage Probability is dependent on Γ (SNR), R (Rate b/s/Hz), α (Cooperation Ratio). Γ is constrained by environmental effects whereas the remaining two parameters are the free parameters. α and Γ will be optimized simultaneously with PSO (Particle swarm optimization) which in turn will Optimize Coded Cooperative Communication [7,10,11].

Optimizing R and α will be viewed as a problem in multimodel space. R and α's optimization will lead to optimization of Outage Probability. Optimization will be achieved with the help of PSO. In this method each entity is referred to as particle and represents a candidate solution. This algorithm is a stochastic optimization technique which is population based. In it each entity is referred to as particle and is having potential to represent a candidate solution. PSO has got its name from the food searching activities of birds. It is a population based search algorithm. In this algorithm each particle flies with dynamically modified adaptable velocity in the multidimensional search space. Inertia, Cognition and Sociality are the three factors which influence the velocity of the flying particle. Inertia behavior of the bird is simulated by the inertial component. Cognition looks after the memory part and it enables particle to find best position in the search space ever visited by it and the third component i.e. Sociality enables the particle to gather information from the other particles about the best position visited by them. The Position corresponding to best fitness is known as P best and overall best of all particles in the population is called Gbest [9]. The working of PSO algorithm is indicated by the flowchart in Fig. 2.

In order to mathematically model PSO it is considered that each particle updates its present state by its inertia, then it changes its state according to the best solution that a particle has achieved so far and finally change the state according to the global solution of the particles in the considered swarm. Following values have been considered for implementing PSO for optimization of Coded Cooperative Communication [11–14] (see Table 1).

In finding the optimized solution choice of parameters is important.

4. Performance evaluation and experimental results

This section represents the simulation and numerical results for the performance and optimization of Coded Cooperative Communication. The Outage probability optimizes which in turn has optimized the Coded Cooperative Communication Scheme. In order to optimize the outage probability free parameters R and α have been optimized. In order to find the optimal values channels between S to d, r to S and S to r are assumed to provide identical behavior.

Fig. 3 depicts the curve between rate and outage probability. For simplification it is assumed that all channels have an equal SNR. The value of SNR is taken 10 db. The graph indicates an exponential increase in the outage probability as the Rate increases. At lower rates outage is controlled but at higher rate abrupt increase in the Outage probability will degrade the performance of Coded Cooperative Communication, as is evident from the graph.

Fig. 4 illustrates Coded Cooperative Communication as a function of level of cooperation α for different values of SNR. The graph indicates that as the value of α increases the outage probability decreases. The higher the value of α the lower will be the Outage Probability.

The problem arises, that behavior of R and α is contradictory to one another. The increase in ones value lead to decrease in Outage Probability where as the other one increases the Outage Probability.

There is a need to find the Optimal values of R and α at which the outage probability will be minimum. In order to evaluate these values PSO algorithm has been used. For obtaining the values a threshold of > 0.5 is considered for both R and α.

Table 2 depicts the comparative optimized and non optimized outage probability. The non optimized outage outage probability has been achieved by placing hit and trial values

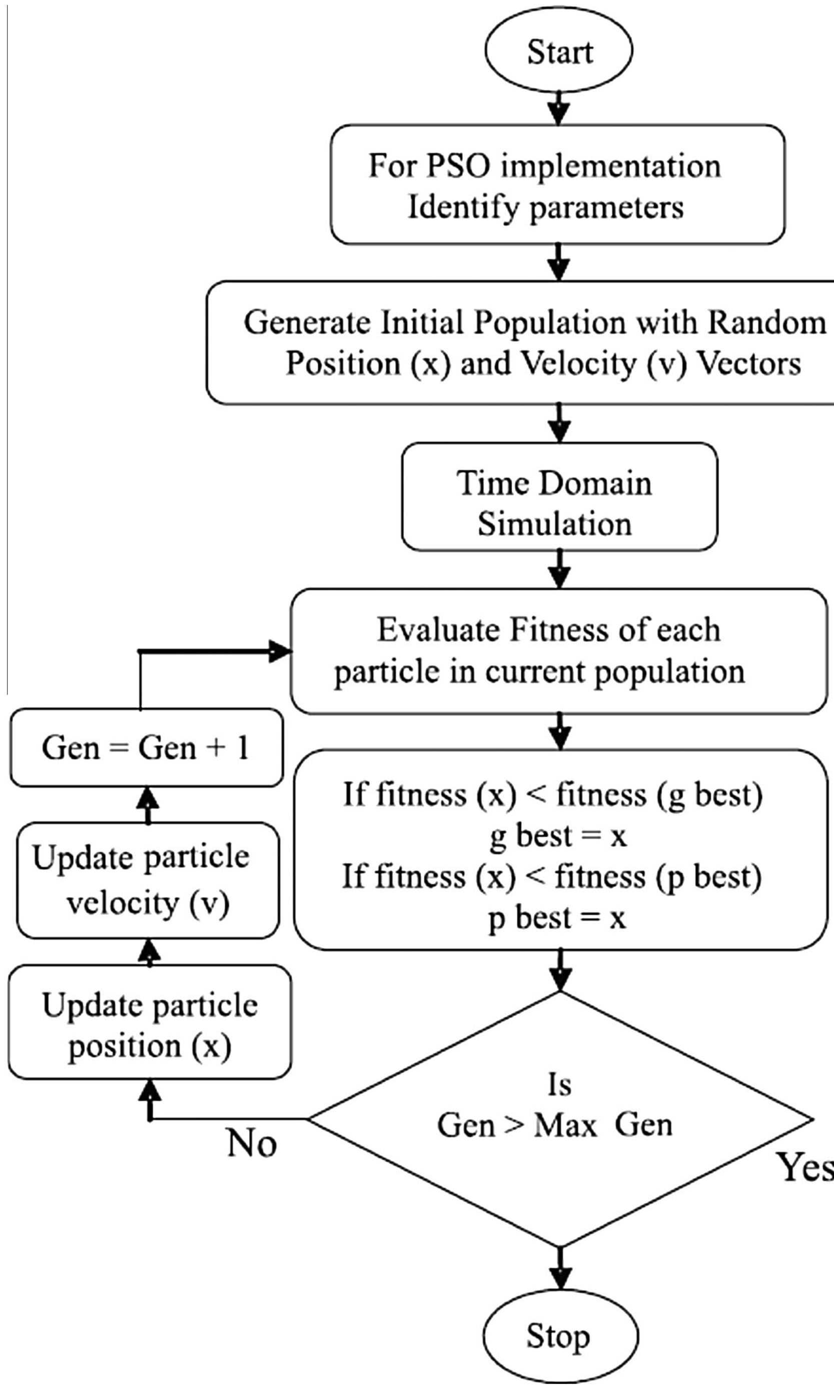

Figure 2 Flowchart of PSO algorithm.

for R and α. The last column of the table indicates the optimized value of the outage probability. This has been achieved by putting the optimal value $R = 0.5817$ b/s/Hz and $\alpha = 0.5845$. These optimized values have been obtained with the help of PSO.

Table 1 Parameters chosen for PSO.

Parameter	Value
Population size	40
Max iteration number it max	100
Acceleration Constant c_1 and c_2	1.4455 each
Initial inertia weight $w_{\max}$	0.9
Final inertia weight $w_{\min}$	0.4

Fig. 5 illustrates the comparative analysis of optimized vs. non optimized Coded Cooperative Communication. For Non Optimized values any hit and trial values of R and α are taken. For Optimized one, optimal values of R and α obtained with the help of PSO are considered. The analysis is done for the three sets i.e. $m = 1$, $m = 2$ and $m = 3$. m indicates the number of cooperating partners. It is clearly shown that the outage probability for the optimized values is less then the outage probability obtained with non optimized hit and

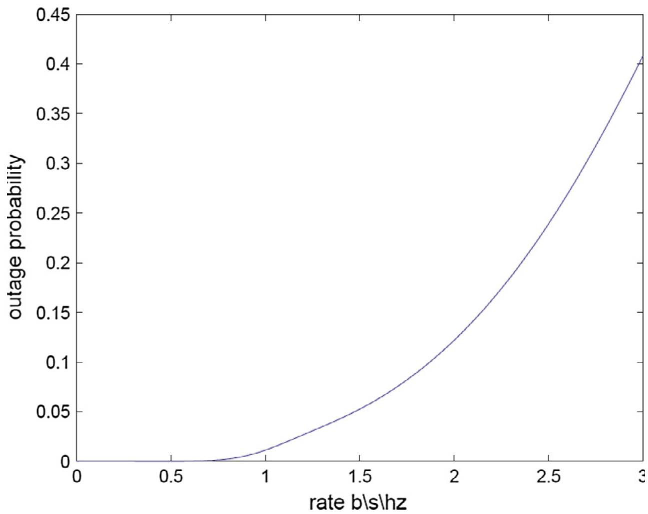

Figure 3 Dependence of outage probability on rate.

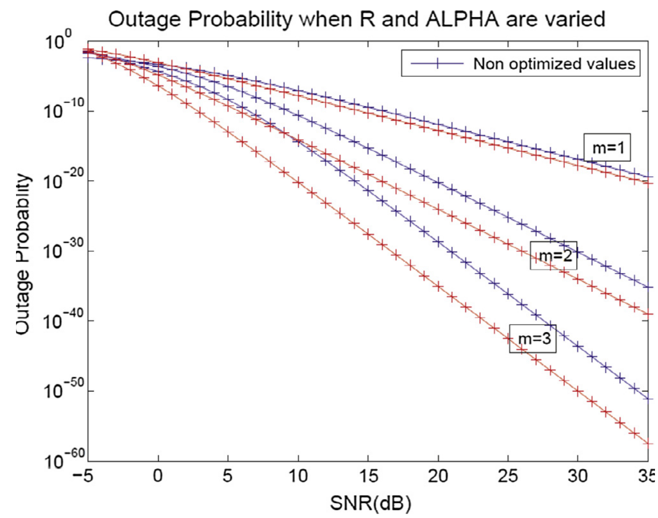

Figure 5 Comparative analysis of optimized vs. non optimized coded cooperative communication.

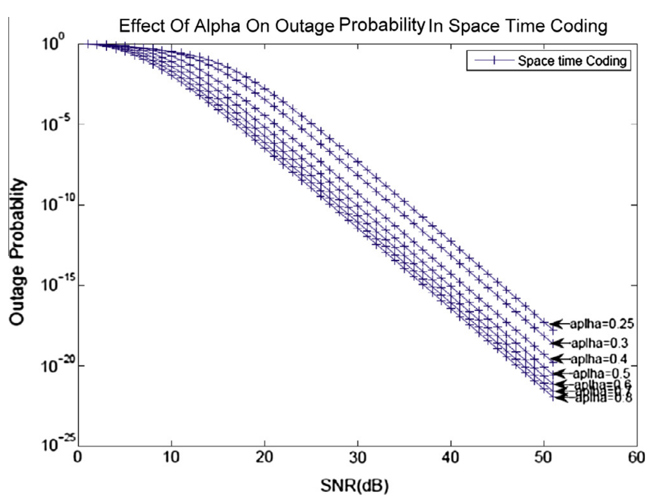

Figure 4 Coded cooperative communication as a function of level of cooperation alpha (symbol) for different values of SNR.

Table 2 Non optimized and optimized outage probability for coded cooperative communication.

S. no.	Optimized/non optimized	α	R	P_{out}
1	Non optimized	0.4293	0.9621	$5135e^{-004}$
2	Non optimized	0.1485	0.8299	0.0109
3	Optimized	0.5845	0.5817	$3.3302e^{-007}$

trial values. The difference becomes more evident as the number of relays increase. For the these variations, in order to calculate optimized value R is kept constant at 0.5845 b/s/Hz and α is kept constant at 0.5817. These are the optimized values which are obtained with the help of PSO.

5. Conclusion

In this paper an approach to implement PSO to optimize outage probability of Coded Cooperative Communication with multiple relays has been proposed. It has been shown that the outage probability of Coded Cooperative Communication with multiple relays under Nakagami-m fading is dependent on R (Rate b/s/Hz), α (cooperation ratio), Γ (SNR). Out of these parameters R and α are the free parameters which may be varied to optimize the outage probability of Coded Cooperative Communication. The behavior of R and α is contradictory to one another. The near optimal solution for this problem has been obtained. The proposed scheme outperforms the non optimized Coded Cooperative Communication. The experimental results indicate the optimized values of Rate (bits/per/Hz) and cooperation ratio (α) reduce the outage probability significantly. The computational complexity of proposed scheme is simpler and the benefits achieved are much higher.

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