Optimal Relay Station Placement in Cooperative Networks using Particle Swarm

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ABSTRACT
This paper explores the application of the particle swarm algorithm for a mixed integer non linear optimization problem in the area of wireless communications. An appropriate relay station placement can enhance the overall capacity of wireless cooperative networks. The specific problem is finding out a realizable and efficient scheme for relay station placement in wireless cooperative networks. This paper defines a method based on particle swarm optimization (PSO) to design and optimize a useful search space for relay station placement and also gives an efficient technique to allocate bandwidth to relay-subscriber association. The proposed algorithm out-performs the previous techniques without compromising overall efficiency. Simulation results guarantees improved performance compared to the existing systems and offers an acceptable trade-off between performance and complexity.

Categories and Subject Descriptors
G.1.6 Optimization - *Nonlinear programming; Integer programming*

General Terms
Algorithms, Design.

Keywords
Relay station Placement, Particle Swarm Optimization

1. RELAY STATION PLACEMENT MODEL

1.1 System Model
Provided the location coordinates for Base Stations (BSs), Subscriber Stations (SSs), Candidate Positions (CPs), and Traffic demand P_n for each SS, objective is to determine the optimal location of RSs. Transmitter power P_t is known and all the relay stations are allocated equal power P_r. This is a resource allocation problem where the objective function (to be maximized) is the capacity enhancement. The decision variables are the RSs locations, their association with SSs and amount of bandwidth allotted to corresponding RSs. Fig.1. depicts the design architecture for a single micro cell with one BS, 'N' number of SSs, 'M' number of CPs and 'K' number of RSs is taken under consideration where K≤M. Distance vectors from BS to SS_n 'd_{sd}', BS to CPs 'd_{sr}', and CPs to SSs 'd_{rd}' are calculated using Euclidian formula.

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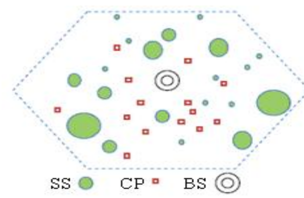

Fig 1. Relay Placement System Model

Theta θ is the transmit power allocation ratio of the source node between the "source-relay" path and "source-destination" path.
In [1], Bin.Lin et al. gave a closed form expression for optimal value of theta for multi relay –multi subscriber wireless cooperative network as follows

$$\theta^* = \begin{cases} \frac{d_{sr}^{\alpha}}{P_s}\frac{2\left(-d_{rd}^{\alpha}P_r+\sqrt{u}\right)}{d_{sd}^{\alpha}d_{rd}^{\alpha}} + \frac{P_s}{d_{sd}^{\alpha}} + \frac{P_r}{d_{rd}^{\alpha}} & \text{for } u > 0 \\ 1 & \text{for } u < 0 \end{cases} \quad (1)$$

Where $u = P_r\left(d_{sd}^{\alpha} - d_{sr}^{\alpha}\right)\left(P_s d_{rd}^{\alpha} - P_r d_{sr}^{\alpha}\right)$ (2)

For simplest three node model, the achievable data rate is given by[2]

$$r_{mn} = \min[C(\frac{P_s}{d_{sd}^{\alpha}N_d} + \frac{P_r}{d_{rd}^{\alpha}N_d} + \frac{2}{N_d}\sqrt{\bar{\theta}\frac{P_sP_r}{(d_{sd}d_{rd})^{\alpha}}}), C(\frac{P_s}{N_r d_{sr}{}^{\alpha}})] \quad (3)$$

The capacity is calculated using Shannon Capacity formula

$$C(x) = 0.5\log(1+x) \quad (4)$$

2.2 Bandwidth Allocation and Fitness function
For enhancing capacity of the network while satisfying each user's demand and bandwidth constraint, *wn* can be allocated as

$$w_n = (B - \sum_{n=1}^{N}\sum_{m=1}^{M}\frac{P_n}{r_{mn}}).(\frac{P_n}{\sum_{n=1}^{N}P_n}) + (\frac{P_n}{r_{mn}}) \quad (5)$$

An expression for fitness function which has to be maximized is

$$C_{ap_{\max}} = \sum_{n=1}^{N}\sum_{m=1}^{M} w_n . r_{mn} \quad (6)$$

3. PSO BASED ALGORITHM FOR RELAY STATIONS PLACEMENT
Particle Swarm Optimization (PSO) technique is inspired by social behavior of bird flocking or fish schooling [3]. A group of particles is initialized by random values as their current positions x_t. In every iteration each particle is updated by the personal best *Pbest*, and the global best *Gbest*. *Pbest* is the best solution (fitness value) one particle has achieved so far [4]. *Gbest* is the best value

obtained so far by any particle in the population[4]. The particle updates its velocity ***v*** and position as follows:

$$v_{t+1} = Wv_t + c_1 r_1 [Pbest_{t+1} - x_t] + c_2 r_2 [Gbest_{t+1} - x_t] \quad (7)$$

$$x_{(t+1)} = x_t + v_{(t+1)} \quad (8)$$

c_1 and c_2 are the scaling constants. W is the inertia weight which controls the trade-off between the global and the local exploration ability of the swarm. Random vectors r_1 and r_2 are uniformly distributed in [0, 1]. With every iteration the particles tend to move towards optimal positions or solution.
The problem search space consists of a set of possible solutions such that a single solution should be vector of size 'Nx1'. Each possible solution should be a combination of 'K' CPs. The PSO based algorithm searches for the optimal set of combinations from the problem space. Initially all the parameters are defined, including problem and PSO parameters. Swarm size is represented by '***P***' with step size '***iterations***'. Then these parameters are initialized with initial values. Current Position values $\boldsymbol{x_t}$ and Velocity vector $\boldsymbol{v_t}$ are set as a vector of size (PxN) with random values between 1 and ***T***(size of search space), current fitness $\boldsymbol{C_t}$ is set as zero vector of size (PxN). Fitness values for first swarm are calculated using (6), velocity, $\boldsymbol{Gbest_t}$ and $\boldsymbol{Pbest_t}$ value is updated using these values. Current position of swarm is updated using new velocity $\boldsymbol{v_{t+1}}$ using (7-8).The loop iterates till the defined limit of swarm steps is reached. The obtained ***Gbest*** in the end gives us the optimal configuration for Relay Station Placement.

4. NUMERICAL RESULTS

Comparing the PSO based RS placement algorithm with previously proposed GA based algorithm [1], following improvement in data rates is achieved. Considering 802.16j micro cell with an OFDM interface with transmit power of BS and RS as 1w and 0.5w respectively, taking path loss exponent value (α) 3 and total allocated bandwidth 20MHz.

TABLE 1. PSO and GA PARAMETERS

PSO PARAMETERS	c_1	c_2	W	iterations	Swarm size
VALUES	2.2	1.9	0.8	8-12	5-200
GA PARAMETERS	P_c	P_m	Population Size		Number of Generations
VALUES	0.8	0.01	8-12		5-200

Achievable data rates are shown in following figure 2.

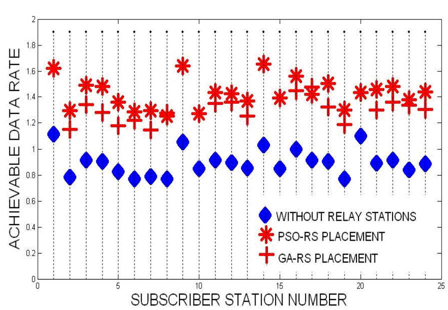

Fig 2. Achievable data rates using GA and PSO based Algorithms

Figure 3. shows the faster and improved convergence of PSO based RS placement algorithm. Monte Carlo simulations show results as given in table 2

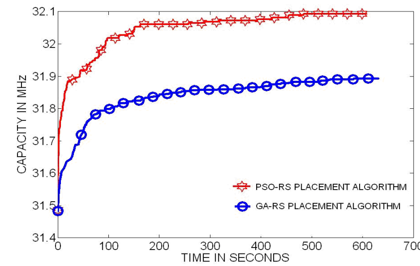

Fig 3. Comparison of Convergence

TABLE 2. PEFORMANCE COMPARISON OF PSO-RS PLACEMENT WITH GA-RS PLACEMENT

GA-RS PLACEMENT				PSO-RS PLACEMENT			
N_{gen}	30	150	300	iterations	30	150	300
N_{pop}	8	10	12	Swarm size	8	10	12
Cap (MHz)	34.4	35.5	35.5	Capacity (MHz)	35.7	36.06	36.06

Complexity for calculating fitness function is given by

$$\Gamma_{cost} = 2N^3K^2 + NK\mu \quad (9)$$

And computational complexity for GA-RS placement and PSO-RS placement can be obtained from

$$\gamma_{GA} = \Gamma_{cost} N_{pop} + N_{gen}(2N_{pop}\Gamma_{cost} + N_{keep}\Gamma_{cost}) \quad (10)$$

$$\gamma_{PSO} = P\Gamma_{cost} + I(P\Gamma_{cost}) \quad (11)$$

TABLE 3. COMPLEXITY COMPARISON OF PSO-RS PLACEMENT WITH GA-RS PLACEMENT

GA-RS PLACEMENT				PSO-RS PLACEMENT			
Ngen	30	150	300	I	30	150	300
Npop	12	12	12	P	12	12	12
Γ_{GA}	$781\,\Gamma_{cost}$	$3901\,\Gamma_{cost}$	$7801\,\Gamma_{cost}$	Γ_{PSO}	$492\,\Gamma_{cost}$	$2412\,\Gamma_{cost}$	$4812\,\Gamma_{cost}$

5. CONCLUSIONS

From obtained results its concluded that data rate can be increased without utilizing extra bandwidth, when Relay Stations are deployed at optimum locations. From upper bound of capacity, operator can know exact number of relay stations to be deployed.
Heuristic algorithms produce efficient results in non linear optimization problems like this one. Results showed that PSO is an efficient technique to solve a MINLP. It converges faster and provides improvement in previously implemented algorithms.
In PSO based RS placement technique there is no need to check multiple constraints for bandwidth limitations and feasibility of configurations in every iteration. PSO-RS placement algorithm is a less complex, faster and more efficient technique for optimal relay station placement in cooperative wireless networks.