SMART CIRCULAR ANTENNA ARRAY BASED COOPERATIVE COMMUNICATIONS USING OPTIMIZATION TECHNIQUE

Ahmed Magdy*, K. R. Mahmoud, S. Sayed, and I. I. Ibrahim

Depart. of Electronics, Communications, and Computers Helwan University, Cairo, Egypt

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ABSTRACT

In this paper, an adaptive protocol to enhance the performance of cooperative wireless communications based on a smart antenna system for a Uniform Circular Array (UCA) using Particle Swarm Optimization (PSO) technique is presented. The results are compared with those obtained using Uniform Linear Array (ULA). In addition, the best strategy for transmission to give the lowest Bit Error Rate (BER) is considered. Simulation results prove enhancement in performance when using the proposed adaptive strategy based UCA smart antenna.

Keywords: Cooperative communication, UCA, WLAN, Smart antenna, PSO.

1. Introduction

The concept of cooperative communication has been proposed to improve link capacity, transmission reliability and network coverage in multiuser wireless communication networks. Different from conventional point-to-point and point-to-multipoint communications, cooperative communication allows multiple users or stations in a wireless network to coordinate their packet transmissions and share each other's resources, thus achieving cooperative diversity or user cooperative diversity [1]–[8].

As a promising application of cooperative communication in multi-rate wireless networks, a low data-rate station can use a neighboring station as a relay to forward its information to destination station [9]–[14]. For example, as shown in Fig. 1, source station-S can use station-R to relay its information to the destination station-D, instead of directly transmitting it to the station-D at a low data-rate. As station-R is located closed to both stations D and S, the transmission data-rate through station-R is higher than the direct transmission rate from station-S to station-D. This relay-type cooperative communication can effectively improve network coverage, transmission data rate, reliability, and system throughput in wireless networks. Further improvements in spectral efficiency and interference cancelation can be achieved by conjunction cooperative communication with smart antenna systems. Smart antennas surprised the world by its improvements in interference reduction and increasing channel capacity [15]–[17]. Adaptive beamforming capability in Smart antenna arrays is very powerful in the suppression of interference and maximizing the gain in the direction of desired signal. To achieve these advantages, some types of optimization should be used. The Particle Swarm Optimization (PSO) algorithm is recognized as a practical and powerful optimization tool for a variety of electromagnetic and antenna design problems [18]–[19]. Compared to other evolutionary algorithms such

Corresponding author.
E-mail address: eng_ahmedmagdy86@yahoo.com

as Genetic Algorithm (GA), the PSO algorithm is much easier to understand and implement and requires minimum mathematical processing.

In this paper, the PSO technique is considered to optimize the array beampattern by determining the weights (phases only) using (UCA). The results are compared with those obtained using (ULA). The main contributions of this paper go through the following three phases:

1) Comparison is made between different geometries for smart antenna with different number of elements.

2) Adaptive cooperative technique based on smart antenna system to improve the performance of the system is presented.

3) Switching technique to select the best strategy for cooperative communication based on signal to noise ratio (SNR) is demonstrated.

Section II of this paper includes the Classical PSO algorithm is presented. Section III gives the system model. An analytical model is derived in Section IV to analyze the SNR for the proposed adaptive cooperative communication based on smart-antenna system. Simulation results are presented and discussed in Section V, followed by the conclusions in Section VI.

2. Classical PSO Algorithm

PSO has surprised the world since its introduction in 1995 by Kennedy and Eberhart as given in [19]. Many researchers have worked on improving PSO performance in various ways and developed many interesting variants. In PSO, each solution is a point in the search space and may be regarded as a "particle" in the algorithm. In general, each particle flies through the D-dimensional problem space by learning from the best experiences of all the particles. Therefore, the particles have a tendency to fly towards better search area over the course of search process. For an D-dimensional problem, the position of the i-th particle is represented as X_{iD} (x_{i1}, x_{i2},... , x_{iD}). Each row of the position matrix represents a possible solution to the optimization problem. The rate of the position change (velocity) for the particle i is represented as V_{iD} (v_{i1}, v_{i2},...,v_{iD}). To update the velocity matrix at each iteration k, every particle should know its personal best and the global best position vectors. The personal best position vector defines the position at which each particle attained its best fitness value up to the present iteration. The personal best position of the i-th particle is represented as $Pbest_{iD}$ ($pbest_{i1}$, $pbest_{i2}$,..., $pbest_{iD}$). The global best position vector defines the position in the solution space at which the best fitness value was achieved by all particles, and is defined by $Gbest_D$ ($gbest_1$, $gbest_2$,. . ., $gbest_D$). The particles are manipulated according to the following equations:

$$v_{iD}{}^{k+1} = w\, v_{iD}{}^{k} + C_1\, rand_1 \left(Pbest_{iD} - x_{iD}{}^{k}\right) + C_2\, rand\,_1\left(gbest_D - x_{iD}{}^{k}\right)$$

$$x_{iD}{}^{k+1} = x_{iD}{}^{k} + v_{iD}{}^{k+1} ,$$

where C_1 and C_2 are the acceleration constants, which represent the weighting of stochastic acceleration terms that pull each particle towards pbest and gbest positions. rand1 and rand2 are three random numbers in the range [0, 1], x is the inertia weight introduced to balance between the global and local search abilities, k is index of iteration and w is the weighting function, can be calculated as function of current iteration number. In our PSO algorithm, the terminology of soft and hard boundary conditions is applied to describe the way in which particles are enforced to stay inside the desired domain of interest.

3. System Model

This research considers, as shown in Fig. 1, a typical cooperative wireless network consisting of a source station-S, relay station-R, and destination station-D. A low data-rate source station continuously evaluates its high data-rate neighboring stations and selects the best one (in terms of effective throughput or time saving) as its potential relay station. Amplify and forward (AF) [20] cooperative protocol is considered in this paper.

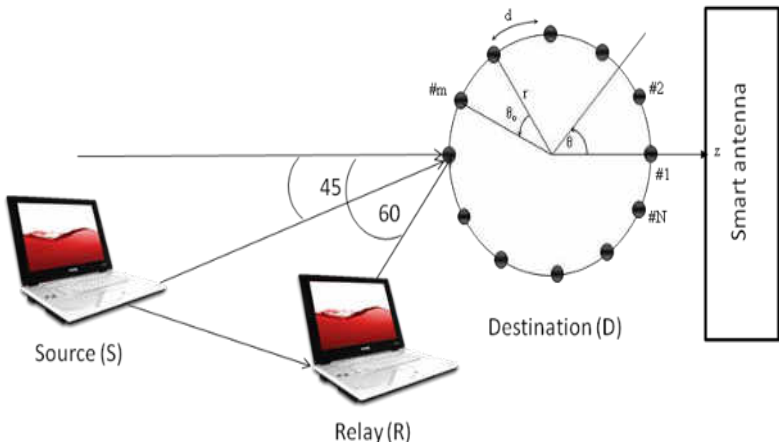


Fig. 1. Wireless cooperative network based on smart antenna

In AF protocol, the relay station (R) amplifies the received signal from the source station (S) and retransmits the amplified signal to the destination station (D). A smart antenna system based on uniform circular array (UCA) with N=12 elements is used at the station-D and these N elements are uniformly distributed with a ring radius $r = (6/2\pi)\lambda$. Where the distance between adjacent elements is $d = 0.5\lambda$, $\theta_0 = 2\pi/N$ is the angle between adjacent elements, λ is wavelength, and θ is an azimuth angle measured from the z-axis. The PSO is considered to adapt the beamforming (feeding of each element) with swarm size of 50 and maximum number of iteration 1000. The communication protocol is as follows: The source (S) sends its signal to both relay (R) and destination (D). After that the relay forwards the received signal after amplifying it to the destination (D). A time division multiple access (TDMA) scheme is used for the signal transmission. In addition, a binary phase shift key (BPSK) is used for noncooperative communication, i.e. direct transmission from (S) to (D), where as Quadrature Phase Shift Keying (QPSK) is used for cooperative transmission through the relay (R).

4. Analysis of Signal to Noise Ratio

This section presents an analytical model for the proposed system. The communication is achieved in two phases. In the first phase the source sends its signal to both relay (R) and destination (D) at 45 degree from the source node and 60 degree from the relay node. The received signal vector y_{sd} at the destination is described by

$$y_{sd} = \sqrt{P_s}\, h_{sd} u_{sd} S + n_1 \quad (1)$$

where P_s is the transmitted power from the source, h_{sd} denotes the source to destination channel impulse response, S denotes the transmitted symbol, u_{sd} is the N-raw vector of the smart antenna system with N-array elements which is calculated by PSO and n_1 is the N-row additive noise vector from (S) to (D). The received signal vector y_{sr} at the relay from the source is given by;

$$y_{sr} = \sqrt{P_s}\, h_{sr} S + n_2 \quad (2)$$

where h_{sr} denotes the channel impulse response from (S) to (R) and n_2 denotes the N-row additive noise vector from (S) to (R). During the second phase, the relay amplifies the received signal from the source and retransmits the amplified signal to the destination. The received signal y_{rd} at the destination is given as [21],

$$y_{rd} = \frac{\sqrt{P_r}\, h_{rd} u_{rd} (\sqrt{P_s}\, h_{sr} S + n_2)}{\sqrt{P_s |h_{sr}|^2 + \sigma^2}} + n_3 \quad (3)$$

P_r is the transmitted power from the relay to destination. h_{rd} is the channel impulse response between the relay and destination, u_{rd} stands for the N-row array vector of the smart antenna system at the relay which is calculated by PSO. n_3 is the N-row additive noise vector over the link between the relay and destination. It is assumed that n_1, n_2, and n_3 are zero mean complex Gaussian vectors with equal variance σ^2. It is also assumed that the stations are non-line of site, hence h_{sr}, h_{sd}, and h_{rd} are modeled as Rayleigh fading channels.($\frac{\sqrt{P_r P_s}}{\sqrt{P_s |h_{sr}|^2 + \sigma^2}}$) is a normalization factor [22].

At the destination, a maximum signal is desired to be obtained. The received signal vectors in 1 and 3 are weighted with two vectors w_1 and w_2 , respectively, as follows;

$$r_1 = W_1 y_{sd} \quad (4)$$

$$r_2 = W_2 y_{rd}, \quad (5)$$

where r_1 and r_2 are the weighted received signals in the first and the second phase, respectively. The optimum weights can be obtained by knowing the channel state information from source to destination and from relay to destination. The source and relay stations obtain the channel state information from the signals sent by the destination (as a new source) to other stations in the network. If this information cannot be updated, pilot signals can be sent from the source to the destination and from the relay to destination. For simplicity, pilot signals are set with unit energy signals, s_p = 1. Then received signals in this acquisition period can be calculated by substituting into equations 1, 2 and 3 to obtain the channel state information.

Equations 4 and 5 are solved by using PSO optimization algorithm for calculating the optimum weight vectors W_1 and W_2. Once r_1 and r_2 have been solved, a Maximum-Ratio Combiner, (MRC), is used to compute the composite received signal, r_c as;

$$r_c = c_{c1} r_1 + c_{c2} r_2 \tag{6}$$

c_{c1} and c_{c2} are the optimum weights of the MRC for equal noise power, which are given by, [22]–[24]

$$c_{c1} = \frac{\sqrt{P_s} h_{sd}^* (w_1^H u_{sd})^*}{||w_1||^2 \sigma^2}$$

$$c_{c2} = \frac{\frac{\sqrt{P_r P_s}}{\sqrt{P_s |h_{sr}|^2 + \sigma^2}} h_{sr}^* h_{rd}^* (w_2^H u_{rd})^*}{\left(||w_2||^2 + \frac{|w_2^H u_{rd} \sqrt{P_r}\, h_{rd}|^2}{P_s |h_{sr}|^2 + \sigma^2}\right)\sigma^2}$$

where H is the complex conjugate transpose. It is assumed that the transmitted symbol s has an average power normalized to one. Therefore, the signal to noise ratio, γ_{sd} and γ_{rd} for the source to destination link and for relay to destination link are computed respectively from the following expressions;

$$\gamma_{sd} = \frac{P_s |h_{sd}|^2 ||u_{sd}^H w_1||^2}{||w_1||^2 \sigma^2} \tag{7}$$

$$\gamma_{rd} = \frac{P_s P_r |h_{sr}|^2 |h_{rd}|^2 ||u_{rd}^H w_2||^2}{((P_s |h_{sr}|^2 + \sigma^2) ||w_2||^2 + P_r |h_{rd}|^2 ||u_{rd}^H w_2||^2)\, \sigma^2} \tag{8}$$

These signals to noise ratios are maximized for the cooperative communication based on the proposed antenna system. An adaptive protocol has ability to maximize the total signal to noise ratio and minimize the Bit error rate [24]. In this protocol the source node calculates the values of γ_{sd} and γ_{rd} by using the prior knowledge of the channel state information, h_{sd}, h_{sr}, and h_{rd}.

The approximate total signal to noise ratio γ_c, of the MRC output under cooperative transmission is given by [22], [23],

$$\gamma_c = \gamma_{sd} + \gamma_{rd} \tag{9}$$

Also the total signal to noise ratio γ_d, under direct transmission, is given by:

$$\gamma_d = \gamma_{sd}, \tag{10}$$

The source node decides to transmit cooperatively if the following condition is satisfied [24]

$$\frac{\gamma_c}{\beta + 1} > \gamma_d \tag{11}$$

where $\beta = 10^{\frac{-\gamma}{10}}$, and γ is the system signal to noise ratio.

5. Simulation Results

To validate the above analysis, a custom event driven simulator using Matlab package and PSO simulator is developed. For simplicity, the power allocated for both source and the relay are normalized to one watt. The Raleigh fading wireless channel is simulated using Jake's model with a normalized Doppler shift of 5000Hz [25]. BPSK and QPSK are used under noncooperative and cooperative transmission, respectively. The channel variances between source and relay, source and destination and relay and destination are set to one, i.e. $\sigma_{sd}^2 = \sigma_{rd}^2 = \sigma_{sr}^2 = 1$. Furthermore, number of pilot signals during the acquisition period is chosen to be 500 bits, the number of array's antenna elements M = 12; and the directional of arrival (DOA) of source-to-destination signal is set to 45^o and a relay-to-destination signal is 60^o. Figure (2) shows the relation between the average BER and the average signal energy to noise spectral density, Average energy to noise ratio (E/N_0) under different modulation techniques with and without smart antenna systems. This figure shows that the smart antenna improves the system performance, the BPSK with UCA smart antenna at, for example, BER = 10^{-2} is better than that the BPSK without smart antenna by around 10 dB. It appears also the QPSK is better than the BPSK at higher E/N_0. Therefore, it is concluded from Figure (2) that QPSK is used for the systems running high SNR whereas BPSK is used for systems running with low SNR. In addition, the smart antenna system is used under low or high SNR regimes. The results given in Figure (3) show the effect of different modulation and smart antenna techniques on the BER versus the average E/N_0. As the E/N_0 increase the BER decreases under all transmission scenarios. However, the performance of the proposed adaptive UCA outperforms the all other protocols for low and high SNR. The reason is that the system uses BPSK with low SNR and switch to QPSK with high SNR as explained in Figure (2). To validate the algorithm, a comparison between the proposed adaptive UCA and ULA are made and show that the proposed UCA is better than the adaptive ULA which used in previous published results by at least 5 dB for the same BER [24]. To be fair the comparison is made in Figure (3) but with 12 elements in two scenarios. Figure (3) shows also that the proposed adaptive UCA is better than the adaptive ULA by at least 3 dB for the same BER.

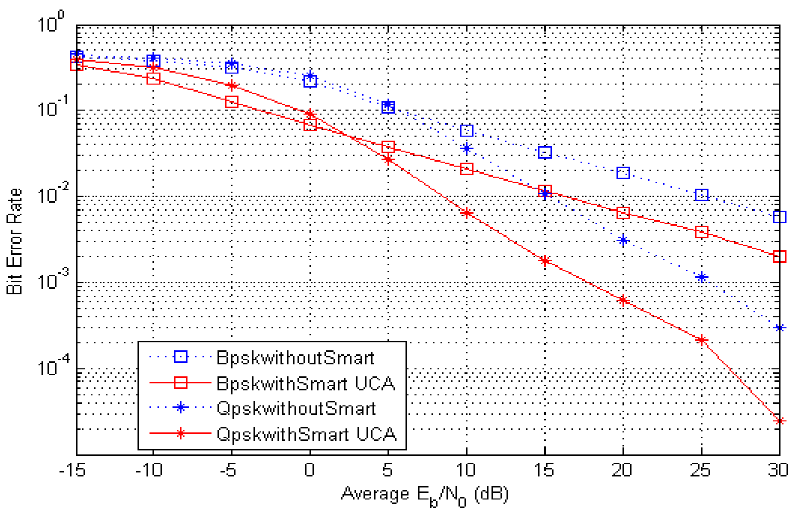


Fig. 2. Average BER vs. E/N_0 for different protocols

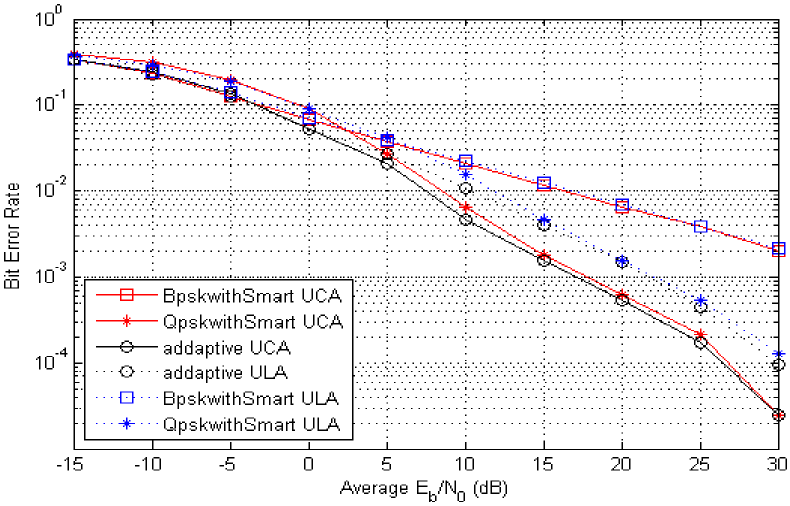
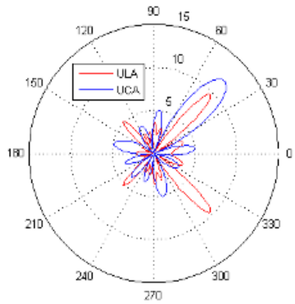
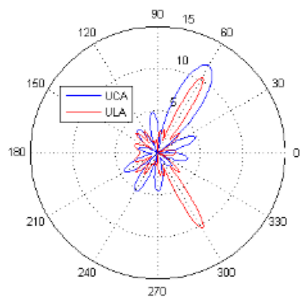


Fig. 3. Average BER vs. E/N$_0$ for different protocols and smart antennas

Figure (4) shows beam patterns comparison of smart antenna for different geometries (UCA and ULA) from relay to destination and from the source to destination. It is found that, both arrays have the capability to direct the main beam toward incoming signal from the source at 45^o and from the relay at 60^o to destination. It is clear that the directed power toward the intended direction using UCA is better than that obtained by ULA by approximately 17 %. Also, it can be noticed that an extra undesired main beam in the broadside direction is obtained in the ULA geometry. In general, the results obtained by UCA are better than those obtained from ULA for both directions.



(a) Direct link



(b) cooperative link

Fig. 4. Polar beam patterns for the smart antenna of 12 elements system in direct and cooperative links (array factor against angle).

6. Conclusions

In this paper, an adaptive cooperative protocol based on smart antenna system is proposed using UCA geometry of 12 elements. The array feeding elements are optimized using the PSO algorithm to synthesize the beampattern. It is found that, the performance of the proposed adaptive UCA outperforms the all other protocols for low and high SNR. The proposed switching technique using adaptive UCA is better than the adaptive ULA by at least 3 dB for the same BER at 10^{-2}.

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مصفوفة الهوائيات الذكية دائرية الشكل القائمة على الاتصالات التعاونية باستخدام تقنية التحسين

الملخص العربى

في هذا البحث تم تقديم بروتوكول تواؤمى لتحسين أداء الاتصالات اللاسلكية التعاونية معتمدا علي نظام الهوائي الذكى على شكل مصفوفة دائرية منتظمة باستخدام طريقة سرب الجسيمات المثلى. كما تمت مقارنة النتائج مع تلك التي تم الحصول عليها باستخدام مصفوفة خطية. وبالإضافة إلى ذلك، تم الاخذ فى الاعتبار أفضل استراتيجية للارسال لتعطى أقل معدل خطأ للبت. و قد أوضحت نتائج المحاكاة تحسين في الأداء عند استخدام استراتيجية التكييف المقترحة معتمدا على الهوائيات الذكية على شكل دائرى منتظم.