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Beam forming and Interference Cancellation in Rician Fading Channel for Uncoordinated Cognitive Networks

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Abstract — Cognitive networks are one of the recent trends in wireless communication. But there are number of disadvantages in these kinds of networks, main one is the interference can be employed by the cognitive client to the primary client or primary client to the cognitive client. Which will totally affect the performance of the entire system, to overcome from these types of complexities we can use a technique called beam forming vector design at both sides. The beam forming vectors are designed such that the interference can be employed by the cognitive transmitter to the primary receiver and the interference can be employed by the primary transmitter to the cognitive receiver is completely nullified while maximizing the rate of both the primary and secondary links. The recommended algorithms also utilize the realizable rates of both links through uncoordinated beam forming.

Keywords:beamforming,cognitive,uncoordinated,networks,interference.

I. INTRODUCTION

The communication process is completed once the receiver has understood the message of the sender [1].Here we are using wireless spectrum of frequency less than 3GHz [2].

A cognitive network consists of a number of traditional wireless service subscribers and they are called as cognitive clients. The conventional wireless examine subscribers have the legacy priority access to the spectrum and are usually called primary clients in this network. Cognitive radio clients presented in this scheme are also known as the secondary clients, are permitted to utilize the spectrum only if communication does not create significant interference to the licensed primary clients.[3]

Beamforming can be employed for radio or sound waves. This is attained by merging the elements in the array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beam forming can be employed at both the transmitting and receiving ends in order to achieve spatial selectivity[4].

Spectrum sensing [5] is the fundamental problem that many researchers attempt to address in the literature. The difficulty is basically sensing where the goal is to find an optimal decision threshold. The design of the threshold creates an interesting trade-off between the probability of miss sensing and the probability of false alarm. A small probability of miss sensing can be achieved by using a low threshold at an expense of high probability of false alarm. Similarly, one can mean a system with a squat probability of false alarm by utilizing a high threshold at an expense of high probability of missed sensing. A highest probability of false alarm is not attractive because the cognitive client remains silent even when the spectrum is not being employed by the primary client. On the other hand, the cognitive client constantly creates interference to the primary client in a system with a high probability of miss sensing. Here they deal with the interference problem in cognitive networks from another perception. There is nix spectrum sensing involved and both primary and secondary clients can transmit simultaneously through the same spectrum without interfering each others. Beamforming is a fine-studied topic in the signal processing writing. It can be employed for either directed transmission or reception of energy in the presence of noise and interference [6]. In current years, beamforming also take part in an important role in multiple antenna system. For instance, beamforming uses channel knowledge at the transmitter to maximize the signal-to-noise ratio (SNR) at the receiver by transmitting in the direction of
the eigenvector analogous to the principal eigenvalue of the channel [7].

In this paper, we consider a cognitive network that consists of a single primary and secondary client. Each client consists of a transmitter and a receiver. Together transmitters and receivers are prepared with multiple antennas and beamforming transmit/receive vectors. In particular, we claim the following
Contributions.

We propose three designs for the beamforming vectors. The beamforming vectors are designed such that the interference employed by the cognitive transmitter to the primary receiver and the interference employed by the primary transmitter to the cognitive receiver is completely nullified while maximizing the rate of both the primary and secondary relations. Simulation results illustrate the effectiveness of the proposed design.

By using multiple antennas at the secondary client, the proposed designs do not want information of the cognitive communication link at the primary client. Actually, the secondary client is unseen to the primary client and the performance of the primary link is not affected by the secondary client at all. This is in contrary to prior work in the

literature which requires coordination between the primary and secondary clients.
We prove that the maximum achievable rate of an cognitive multiple-input multiple output (MIMO) system under a zero interference condition is the same as the maximum achievable rate of an interference-free multiple-input single output (MISO) system which employs an optimal transmit beamforming vector.

II. Network and Channel Models

Consider a cognitive network with a single primary client and a single cognitive (secondary) client as depicted in Fig. 1. Each client consists of a transmitter and a receiver. The primary transmitter and receiver are equipped with *N*P *t* and *N*P *r* antennas, respectively. Likewise, the secondary transmitter and receiver are equipped with *N*C *t* and *N*C *r* antennas, respectively. Unless stated otherwise, *N*C *t* ≥ 2, and *N*C *r* ≥ 2 is assumed.

Consider a cognitive network with a single primary client and a single cognitive (secondary) client as depicted in Fig. 3.Each client consists of a transmitter and a receiver. The primary transmitter and receiver are equipped with $\mathrm{N}_t^P$and N_t^pantennas, respectively. Receiver is denoted by W whereas the one between the secondary transmitter and receiver is denoted by H. The interference channel from the primary transmitter to the secondary receiver is denoted by D and the interference channel from the secondary transmitter to the primary receiver is denoted by G.

We model the individual channel elements in W, H, D, and G. The primary transmitter employs a beam forming vector u for the transmission of its data symbol xP. At the cognitive link, the transmitter employs a beam forming vector f for the transmission of its data symbol Xc. Xp and Xc are assumed to be complex zero-mean unit variance random variables. Furthermore, let **v** and **t** be the receiver combining vector for the primary and secondary receiver, respectively

$$\{V_{opt,}f_{opt,}t_{opt,}u_{opt}\} = argmax\{log_2(1+SINR_P) + log2(1+SINRC)\}$$
$$\begin{cases} v^*Gf = 0 \; and \; t^*Du = 0 \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases} \quad (1)$$
$$\{V_{opt,}f_{opt,}t_{opt,}u_{opt}\} = argmax\{log_2(1+SINR_P) + log2(1+SINRC)\}$$
$$\begin{cases} f \in Null(v^*Gf) \; andt \in Null(Du) \\ u^*u = f^*f = v^*v = t^*t = 1 \end{cases} \quad (2)$$

multiplexing.2 We consider single stream of information only for ease of conveying the main idea. At the cognitive link, the transmitter employs a beamforming vector ***f*** for the transmission of its data symbol *x*C. *x*P and *x*C are assumed to be complex zero-mean unit variance random variables.
Furthermore, let ***v*** and ***t*** be the receive combining vector for the primary and secondary receiver, respectively.
Let *P*P and *P*C be the transmit power at the primary and secondary transmitter, respectively, the received signal at the primary receiver and the secondary receiver are given respectively by

$$r_p = \sqrt{p_p}v^*wux_p + \sqrt{p_p}v^*Gfx_c + v^*n_p \quad (3)$$

$$r_c = \sqrt{p_c}t^*Hfx_c + \sqrt{p_c}t^*Dux_p + t^*n_c \quad (4)$$

The elements in the noise vectors ***n***P and ***n***C are modelled as i.i.d. zero-mean complex Gaussian random variables with variance *σ*2P and *σ*2C , respectively. The resulting signal-to interference- plus-noise ratio (SINR) of the primary and cognitive links are given by

$$\mathrm{SINR_P} = \frac{\mathrm{P_P V^*W^*UU^*WV}}{\mathrm{P_P v^* Gff^* G^* v + v^* v\sigma_p^2}} \quad (5)$$

$$\mathrm{SINR_C} = \frac{\mathrm{P_C t^* H^* ff^* Ht}}{\mathrm{p_C t^* Duu^* D^* t + t^* t\sigma_C^2}} \quad (6)$$

respectively. It is obvious from (5) and (6) that in order to achieve zero interference, the beamforming vectors ***v***, ***f***, ***t***, and ***u*** have to be designed such that ***v**Gf*** = 0 and ***t*Du*** = 0. In addition to guarantee zero interference, our goal is also to maximize the sum rate. For a single stream transmission,the sum rate is given by

$$\mathrm{R_S} = \log_2(1+\mathrm{SINR_P}) + \log_2(1+\mathrm{SINR_C}) \quad (7)$$

Therefore, the design problem can be mathematically formulated as (1) given at the top of this page. In the next section, we present three solutions to the above optimization problem assuming that the primary client has completely no knowledge of the secondary client while achieving zero interference at both receivers.

III. Beamforming and Vector Design

In the cognitive network the secondary client (cognitive client) is transparent to the primary client since the performance of the primary client should not be affected by the secondary link. In these networks zero interference can be achieved by appropriately designing v or f and t or u. To achieve zero interference caemployed to the primary receiver, these secondary transmitter can beam form in the null space of v*G.

Likewise, at the cognitive receiver the receiver beamforming vector t can be designed such that it is in the null space of Du in order to avoid the interference employed by the primary transmitter. Note that v*G is a 1 × $\mathrm{N_t^c}$ vector and the dimension of its null space is $\mathrm{N_t^c}$−1. Similarly, the dimension of Du is $\mathrm{N_r^c}$× 1 and the dimension of its null space is $\mathrm{N_r^c}$− 1. The rate of the primary client can be maximized by appropriately designing **v** and **u**. Since no interference is created at the primary client and the only constraint for the beamforming vectors **v** and **u** is the energy constraint.

The spectral efficiency can be maximized by maximizing the SINR due to the monotonic property of the logarithm function. It is well known that the SINR maximizing receive beamformer for a point-to-point link is the maximal ratio combining beamformer.

The basic beamforming vectors are given by

$$\{\mathrm{f_{opt}, t_{opt}}\} = \underset{\mathrm{f,t}}{\mathrm{argmax}} \left\{ \frac{\mathrm{p_C t^* Hff^* H^* t}}{\mathrm{t^* t\sigma_C^2}} \right\}$$

(8)

$$\text{subject} \quad \begin{cases} f \in \text{Null}(v_{opt}^{*}G) \text{and } t \in \text{Null}(Du_{opt}) \\ f^{*}f = t^{*}t = 1 \end{cases}$$

(9)

The signal received at the primary receiver is rearranged according to the beamforming vectors, and given by

$$r_p = \frac{\sqrt{p_p}\, u^{*}W^{*}Wu}{\sqrt{u^{*}W^{*}Wu}} xp + \frac{u^{*}W^{*}}{\sqrt{u^{*}W^{*}Wu}} np \quad (10)$$

$$SINR_P = \frac{p_p u^{*}W^{*}Wu}{\sigma_P^2} \quad (11)$$

To maximize the SINR of the cognitive communication link, the design of ***f*** and ***t*** is not as flexible as the one for ***v*** and ***u***. This is because the feasible value of ***f*** and ***t*** is now constrained by the zero interference requirement. Specifically, the optimal beamformers can be obtained by solving the optimization problem (8) and (9).

The rate of the primary client can be maximized by appropriately designing ***v*** and ***u***. Since no interference is created at the primary client and the only constraint for the beamforming vectors ***v*** and ***u*** is the energy constraint, standard approaches in existing literature can be employed to design ***v*** and ***u*** to maximize the rate of the *N*P *t* × *N*P *r* interference free MIMO link [8], [9].

A.Method 1. Discrete search

Let F and T be the set of basis vectors which spans the null space of $v_{opt}^{*}G$ and D_{uopt} respectively. Note that the cardinality of F and T are N_t^c−1 and N_r^c−1, respectively. The instantaneous SINR of the cognitive link given by

$$SINR_C = \frac{P_C t^{*}Hff^{*}H^{*}t}{t^{*}t\sigma_C^2} \quad (12)$$

And it can be maximized by performing an exhaustive search in F and T. Both the secondary beam forming vectors should be designed with interference signal as nullified condition. Beam forming vectors are selected to increase the maximum sum rate of the entire system.

$$\{f_{discrete}, t_{discrete}\} = \underset{f \in F, t \in T}{\text{argmax}} \left\{ \frac{p_c t^{*}Hff^{*}H^{*}t}{t^{*}t\sigma_c^2} \right\} \quad (13)$$

Note that for $N_t^c = N_r^c = 2$, there is only one vector in the set F and T. In general, $(N_t^c - 1)$ X $(N_r^c - 1)$ Computations are required to obtain the best beamformers **f** discrete and **t** discrete. Although zero interference can always be guaranteed at both receivers by selecting the beamformer pair's f, **t** as in the above equation, the obtained solution is not optimal in the sense of maximum sum rate because the search in above is not carried out over the entire null space.

B.Method 2. Gradient Method

Since any vector in the null space of $v_{opt}^{*}G$ and D uopt satisfies the zero interference condition, there could be potentially other vectors in those spaces which yield a higher SINRC than f discrete and t discrete. Suppose the columns of $\widehat{G}$ and $\widehat{D}$ contain the basis vectors of the null space of $v_{opt}^{*}G$ and D uopt, respectively. The optimal beamformers are in the form of

$$f_{grad} = \frac{\widehat{G}a}{\sqrt{a^{*}a}} \quad (14)$$

And for t is given by

$$t_{grad} = \frac{\widehat{D}b}{\sqrt{b^{*}b}} \quad (15)$$

Where $a \in \mathbb{C}^{(N_t^c-1)*1}$ and $b \in \mathbb{C}^{(N_r^c-1)*1}$. The constrained optimization problem in the above equation can now be formulated as an unconstrained one whose goal is to find $a \in \mathbb{C}^{(N_t^c-1)*1}$ and $b \in \mathbb{C}^{(N_r^c-1)*1}$ such that the objective function in the above equation is maximized.

The equations is given by

$$\{a_{opt}, b_{opt}\} = \underset{a,b}{\text{argmax}} \left\{ \frac{p_c b^{*}\widehat{D}^{*}H\widehat{G}aa^{*}\widehat{G}^{*}H^{*}\widehat{D}b}{b^{*}ba^{*}a\sigma_c^2} \right\} \quad (16)$$

The gradient algorithm is given by

$$\begin{bmatrix} a[i+1] \\ b[i+1] \end{bmatrix} = \begin{bmatrix} a[i] \\ b[i] \end{bmatrix} + \mu \begin{bmatrix} \partial f(a[i],b[i])/\partial a[i]^{*} \\ \partial f(a[i],b[i])/\partial b[i]^{*} \end{bmatrix} \quad (17)$$

In the equation 'i' is the iteration index and μ is the adaptation step size. Furthermore the two gradients in the above equation can be rewrite as

$$\frac{\partial f(a[i],b[i])}{\partial a[i]^{*}} = K\left[\left((b^{*}ba^{*}a)\right)\left(\widehat{G}^{*}H^{*}\widehat{D}bb^{*}\widehat{D}^{*}H\widehat{G}a\right) - \left(a^{*}\widehat{G}^{*}H^{*}\widehat{D}bb^{*}\widehat{D}^{*}H\widehat{G}a\right)(b^{*}ba)\right] \quad (18)$$

$$\frac{\partial f(a[i],b[i])}{\partial b[i]^{*}} = K\left[(b^{*}ba^{*}a)\left(\widehat{D}^{*}H\widehat{G}aa^{*}\widehat{G}^{*}H^{*}\widehat{D}b\right) - \left(b^{*}\widehat{D}^{*}H\widehat{G}aa^{*}\widehat{G}^{*}H^{*}\widehat{D}b\right)(a^{*}ab)\right] \quad (19)$$

Furthermore, the two gradients are explained in the previous section can be explained in above, from which 'K' is an irrelevant constant. The time index i is dropped in the two gradients for case of presentation. In the next section some guidelines in choosing and adaptation constant μ and the initial values a [1] and b [1] are provided.

C.Method 3. Optimal Solution for $N_r^c = 2$

As mentioned in the last section, there is no closed-form solution to the above equation. However, if we fix the number of receive antennas of the cognitive client to two, the joint optimization in the equation becomes a single (vector) variable optimization problem and a closed-form solution is feasible. The equation can be rewrite as

{,} = {

$$\{f_{opt}, t_{opt}\} = \underset{f,t}{\text{argmax}} \left\{ \frac{p_c f^{*}H^{*}tt^{*}Hf}{t^{*}t\sigma_c^2} \right\} \quad (20)$$

Assuming the same constraints explain in above. Suppose $N_r^c = 2$ the null space of D uopt is one dimensional. Assume that the null space of D uopt is spanned by t_0 and therefore, the receive beamforming vector at the cognitive receiver is given by $t_{opt} = t_0$. Recall that the optimal beamformers are in the form of above equations

$$\bar{h} = \hat{G}^* H^* t_o$$

The optimization problem in the above equation becomes

$$\{a_{opt}\} = argmax\left\{\frac{P_c a^* \bar{h}\bar{h}^* a}{a^* a \sigma_c^2}\right\} \quad (21)$$

By using the above formulae is also known as the generalized Rayleigh fading quotient and by invoking the Rayleigh's principle it is bounded by

$$\frac{P_c \lambda_{min}(\bar{h}\bar{h}^*)}{\sigma_c^2} \leq SINR_C = \frac{P_c a^* \bar{h}\bar{h}^* a}{a^* a \sigma_c^2} \leq \frac{P_c \lambda_{max}(\bar{h}\bar{h}^*)}{\sigma_c^2} \quad (22)$$

Therefore $SINR_C$ can be maximized by choosing a_{opt} to be the eigen vector corresponding to the maximum eigen values of $\bar{h}\bar{h}^*$. It is interesting to note that although there is no constraint on $a \in \mathbb{C}(N_c^t - 1) * 1$, the optimal solution a_{opt} is always a unit vector and consequently, we can obtain the optimal transmit beamforming vector directly by $f_{opt} = \hat{G} a_{opt}$ without the normalization in the above equation

IV. NUMERICAL AND SIMULATION RESULTS

In this model, we present some simulation results. Since the performance of the primary link is independent of the secondary link, without loss of generality we assume $N_t^p = N_r^p = 1$ for all results shown in this section for simplicity. We first consider an example of the gradient algorithm presented in the above sections. For the initialization of the gradient algorithm the below equations are assumed.

$$a[1] = \frac{1_{N_t^c - 1}}{\sqrt{N_t^c - 1}} \quad (23)$$

$$b[1] = \frac{1_{N_r^c - 1}}{\sqrt{N_r^c - 1}} \quad (24)$$

For the initialization of gradient algorithm we use the above equation as an initial value. Furthermore, μ = 0.05 is employed for the adaptation size. These parameters are selected based on extensive simulations to ensure rapid convergence of the algorithm. Based on our observation, the initial values a [1] and b [1] has little effect on the convergence behavior of the algorithm. Therefore, we chose the all one vectors for convenient. We note that another convenient choice would be the vectors obtained by above method. In this project the simulation and results are obtained only by making assumptions on channel matrix. And the channel matrices are created according to satisfy the Rayleigh principle.

With the chosen parameters, it was found that the algorithm generally converges within 100 iterations. As an example, we consider one realization of the channels shown in assuming N_t^c= 3 and N_r^c = 2, The output of the algorithm at *i* = 500 is given by the above equation. The corresponding convergence behavior is shown in below figure. Furthermore, with the channel realizations in $\hat{G}$ *and* $\hat{D}$and are given by the above equations. Furthermore, with

G =[0.5140 + j 0.5567, −0.2146 − j 0.6282, 0.2078 + j 0.8111]
D =[0.5072 + j 0.3457, 1.1528 + j 0.7316]*
H =[−0.7758 − j 0.9689, −0.5724+ j 1.2102, −2.0819 + j 0.0723
1.0171 + j 0.1707, 0.2299 − j 0.2257, −0.5338 − j 0.2212]
a[500] = [0.3984 − j 0.2189, 0.6436 + j 0.2190]
* and ***b***[500] = [0.7071]
fgrad =[−0.1073+ j 0.2877, 0.6264 + j 0.1824, 0.6929]*
tgrad =[0.9116 + j 0.0299, −0.4100]*
Gfgrad = ***t****grad***D*** = ***Gf***opt = ***t****opt***D*** = 0.

The sum rate RS in (7) as a function of the average SNR _ E{SINRP} = E{SINRC} for NCt = 3 and NCr = 2is shown in Fig. 3. Note that since NPt = NPr = 1, W is simply a scaler and uopt = 1 and vopt = W/√W∗ W can be employed for the primary link. The three methods presented in Section III are employed to generate the beamformers. For comparison, the sum rate results of a network with an 1 × 1 primary link and a 1×1, 3×2, and 2×1 secondary link system
assuming that the two links do not interfere with each others are also shown. In these scenarios, the beamformers f and t are designed only to maximize the rate of the secondary link assuming single stream without any interference nullification constraint. This essentially gives us an idea of the price has to be paid for interference nullification. As expected, the sum rate performance of beamformers obtained from Method 2 and Method 3 are identical and are better than the performance of the ones obtained from Method 1. In general, Method 2 and Method 3 are 1.4 dB better than Method 1. Note also that the results obtained for Method 2 and Method 3 coincide with the 2 × 1 curve. This is in accordance with Theorem 1 presented in Section III. Finally, the gap between the 3 × 2 curve and Method 3 curve is about 4.5 dB and it essentially represents the price that has to be paid in order to avoid cross

fopt =[−0.0089+ j 0.3070, 0.6518 − j 0.0290, 0.6559 − j 0.2232]* topt =[0.9116 + j 0.0299, −0.4100]*

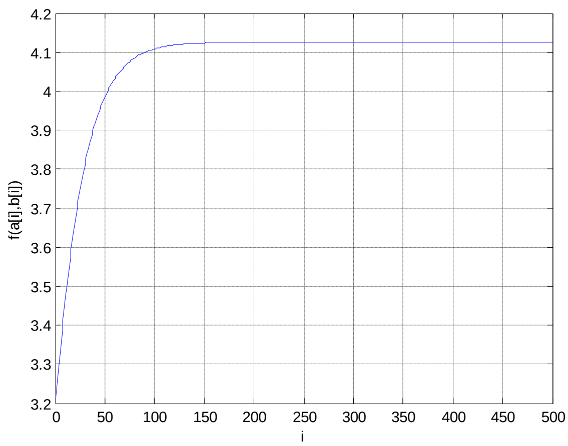

Fig. 2. *f*(***a***[*i*], ***b***[*i*]) vs. iteration index *i* for the channels t

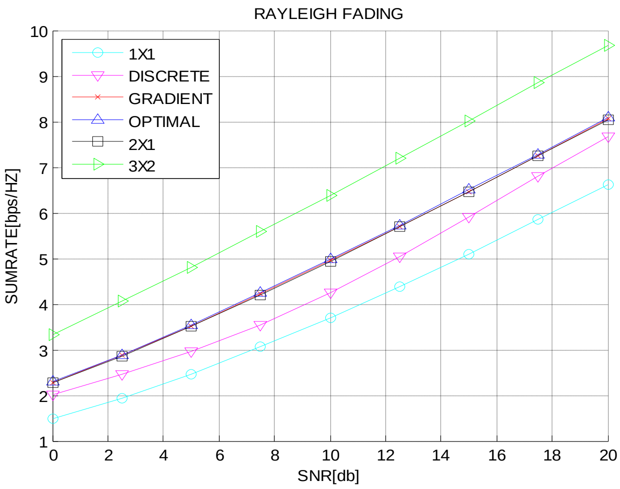

Fig. 3. Sum rate comparisons vs. SNR for a network with *NCt* = 3.

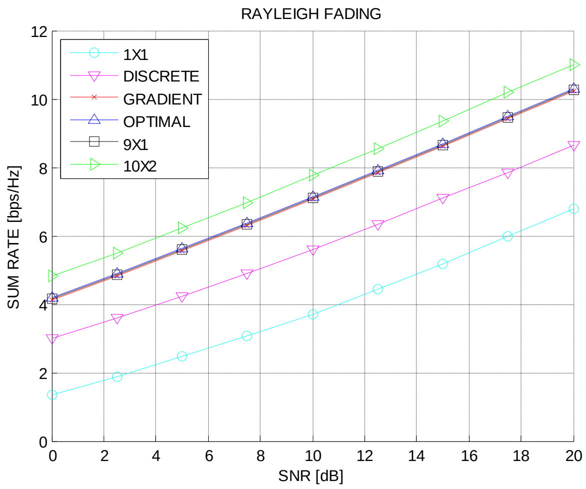

Fig. 4. Sum rate comparisons vs. SNR for a network with *NCt* = 10

interference between the primary and secondary links. In the last example shown in Fig. 4, we consider a system with *NC t* = 10 assuming the rest of the parameters unchanged as in Fig. 3. Similar observation as in Fig. 3 can be made. In this case, Method 2 is about 5 dB better than Method 1. The curve for Method 2 and Method 3 coincides with the 9×1 curve as expected. Finally, it is noted that the gap between the Method 3 and 10 × 2 curves reduces to about 2 dB. This is due to the diminishing of return phenomenon observed generally in MIMO system as the number of antennas increases

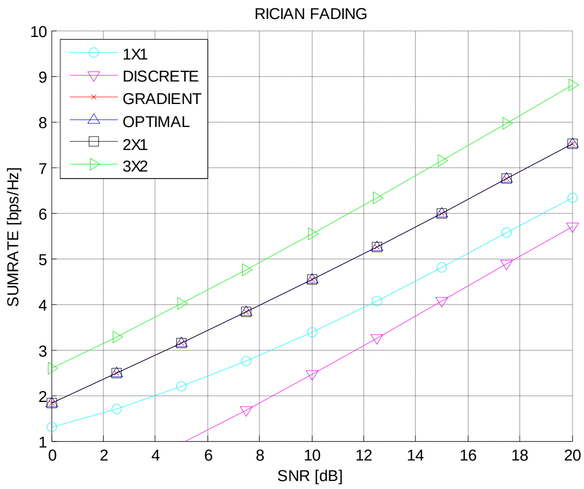

Fig. 5. Sum rate comparisons vs. SNR for a network with *NCt* = 10
In Rician fading channel

V. CONCLUSION

In this literature, we considered extension of Rayleigh channel to racian channel and interference cancellation and achievable rate maximization via uncoordinated beam forming in a cognitive network which consists of a primary and secondary client. The secondary (cognitive) client was allowed to transmit concurrently with the primary licensed client. The beam forming vectors of the cognitive client were designed such that the interference is completely nullified both at the primary and secondary receivers while maximizing the rate of the cognitive link. Since no interference is created at the primary receiver, traditional approaches can be employed to design the beam forming vectors or pre-coding matrices of the primary client. Three approaches were proposed for the design of the beam forming vectors of the cognitive link. Finally, it is noted that we motivate the uncoordinated beam forming and rate maximization concept in a cognitive network. However, the results can also be applied to practical systems, e.g., small cell deployment in a macro network.

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