WHEN DOES INTERFERENCE NOT REDUCE CAPACITY IN MULTI-ANTENNA NETWORKS?

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ABSTRACT

Multi-user interference induces performance loss in terms of BER and channel capacity when present in a communication system. Nevertheless multi-user interference can be suppressed via signal processing techniques so to improve performance. In fact, the presence of this interference reduce the channel capacity region [2]. In this work the conditions allowing perfect interference cancellation are derived so to arrive at the same capacity region of an interference-free network.

1. SYSTEM MODEL

The system model we consider is based on a network possibly operating in "ad-hoc" mode composed by $n^{\star}$ transimit/receive pairs. The g-th transmitter is supposed to be equipped with t_g transmit antennas while the corresponding g-th receiver is supposed equipped with r_g receive ones. Furthermore the distance between two nodes f-th and g-th is represented by $l(f,g)$ expressed in meters. The link from the g-th transmitter to g-th receiver can be analytically modelled as

$$\underline{\mathbf{y}}^{(g)}(n) = [l(g,g)]^{-\beta/2}\frac{1}{\sqrt{t_g}}\left(\mathbf{H}^{(g,g)}\right)^T\underline{\varphi}^{(g)}(n)+ \sum_{\substack{f=1\\ f\neq g}}^{n^{\star}}\frac{[l(f,g)]^{-\beta/2}}{\sqrt{t_f}}\left(\mathbf{H}^{(f,g)}\right)^T\underline{\varphi}^{(f)}(n)+\underline{\mathbf{w}}^{(g)}(n), 1\leq n\leq T_{pay} \quad (1)$$

where the parameter β takes into account for the path loss, $\underline{\varphi}^{(g)}(n) \triangleq \left[\varphi_1^{(g)}(n),\cdots,\varphi_{t_g}^{(g)}(n)\right]^T \in \mathbb{C}^{t_g}$ is the vector collecting the t_g complex samples emitted by the t_g antennas at the time instant n ($1\leq n\leq T_{pay}$, where T_{pay} is the payload length). About the channel $\mathbf{H}^{(g,g)}$ it is assumed to collect the $(t_g\times r_g)$ channel path gains from the g-th transmitter to g-th receiver modelled as statistically independent zero-mean unit-variance complex Gaussian r.v.s. In addition the vector $\underline{\varphi}^{(f)}(n) \triangleq \left[\varphi_1^{(f)}(n),\cdots,\varphi_{t_f}^{(f)}(n)\right]^T \in \mathbb{C}^{t_f}$ is the vector gathering the t_f complex samples emitted by the t_f antennas of f-th *interfering* transmitter. Furthermore the channel $\mathbf{H}^{(f,g)}$ presents the same statistic properties of $\mathbf{H}^{(g,g)}$ and its dimensions are $(t_f\times r_g)$ and it models the "interference channel" from f-th transmitter to g-th receiver. Lastly $\underline{\mathbf{w}}^{(g)}(n) \triangleq \left[w_1^{(g)}(n),\cdots,w_{r_g}^{(g)}(n)\right]^T \in \mathbb{C}^{r_g}$ is the vector collecting the mutually-independent, zero mean, white noise Gaussian samples with variance equal to $\mathcal{N}_0^{(g)}/2$. In this work the following assumptions are considered:

Assumption 1 *Each channel coefficient* $h_{ji}^{(f,g)}\in\mathbb{C}, 1\leq j\leq r_g, 1\leq i\leq t_g, 1\leq f,g\leq n^{\star}$, *is a zero mean unit variance complex Gaussian r.v. with real and imaginary part assumed independent with variance equal to* $1/2$.

Assumption 2 *All the channel coefficients* $h_{ji}^{(f,g)}\in\mathbb{C}, 1\leq j\leq r_g, 1\leq i\leq t_g, 1\leq f,g\leq n^{\star}$, *are statistically independent both from the payload samples* $\{\varphi_i^{(g)}\in\mathbb{C}, 1\leq n\leq T_{pay}, 1\leq i\leq t_g, 1\leq g\leq n^{\star}\}$ *and the noise samples* $\{w_j^{(g)}\in\mathbb{C}, 1\leq n\leq T_{pay}, 1\leq j\leq r_g, 1\leq g\leq n^{\star}\}$ *present at the receive antennas.*

Assumption 3 *All the noise samples* $\{w_j^{(g)}\in\mathbb{C}, 1\leq n\leq T_{pay}, 1\leq j\leq r_g, 1\leq g\leq n^{\star}\}$ *are mutually-independent with respect to the* j,g,n *indexes. Furthermore they are independent from the payload samples* $\{\varphi_j^{(g)}(n)\}$.

Assumption 4 *The channel path gains* $\{h_{ji}^{(f,g)}\}$ *are constant during a time duration equal to* T_{pay} *(block fading model).*

Assumption 5 *The g-th receiver* $R_g, (1,\leq g\leq n^{\star})$ *perfectly knows the* $n^{\star}$ *matrices* $\boldsymbol{H}^{(1,g)},\cdots,\boldsymbol{H}^{(g,g)},\cdots,\boldsymbol{H}^{(n^{\star},g)}$ *of the reference link* $g\rightarrow g$ *and the interfering ones* $f\rightarrow g, (f=1,\cdots,n^{\star}, f\neq g)$.

Assumption 6 *The g-th transmitter* T_g $(g=1,\cdots,n^{\star})$ *does not know the channel matrices* $\boldsymbol{H}^{(g,i)}, 1\leq i\leq n^{\star}$.

Assumption 7 *No cooperation among nodes is considered.*

From eq.(1) it derives that the signal-to-noise-interference ratio $\gamma_j^{(g)}$ for the g-th receiver and per received sample is given by

$$\gamma_j^{(g)} \equiv \gamma_j = \frac{P^{(g)}l(g,g)^{-\beta}}{\mathcal{N}_0^{(g)}+\sum_{\substack{f=1\\ f\neq g}}^{n^{\star}} l(f,g)^{-\beta}P^{(f)}}\ , g=1,\cdots,n^{\star}. \quad (2)$$

Obviously the term in (2) is bounded because each of the emitted powers $P^{(g)}, g = 1, \cdots, n^\star$ are bounded. In fact we have that

$$\text{Tra}\left[\mathbf{R}_{\varphi}^{(g)}\right] \leq t_g P^{(g)} \quad g = 1, \cdots, n^\star \tag{3}$$

where $\mathbf{R}_{\varphi}^{(g)}$ is the $(t_g \times t_g)$ shaping matrix (spatial covariance matrix of emitted signals) at the g-th transmitter defined as

$$\mathbf{R}_{\varphi}^{(g)} \triangleq \text{E}\left\{\underline{\varphi}^{(g)}(n)\left(\underline{\varphi}^{(g)}(n)\right)^{\dagger}\right\}. \tag{4}$$

2. CAPACITY REGION FOR A MULTI-ANTENNA NETWORK

Let us consider the general case of $n^\star$ transmit/receive pairs since this case represents the general problem and the expression for the received sequence by the g-th receiver is still given by eq.(1) where $f, g = 1, \cdots, n^\star$. About the definition of capacity region [2] we have

Definition 1 (Capacity Region of Interference Channel) *The Capacity Region $\mathcal{C}$ of the network is defined as the region including all the $n^\star$-ples of rates $R(1), R(2), ..., R(n^\star)$ that are sustainable by the network.*

The presence of interference, without any interference cancellation policy, reduce the capacity region of the interference free-channel [1,2], so we can affirm that $\mathcal{C} \subseteq \mathcal{C}_0$ and the ultimate goal is to determine the conditions allowing $\mathcal{C} \equiv \mathcal{C}_0$.

2.1. Assumptions about interference cancellation

The first problem to be solved deals with the sorting of the signals to be decoded and subtracted at receive side. Since the decoding of the f-th interferer is affected by the presence of other users signals, it is reasonable that the receiver first decodes the user signal received with more power and as last the user with less power. This slot-by-slot solution is employed in multi-user decoders based on progressive interference cancellation (ZF-DFE, see [7]) but it requires continuous update of the Signal-to-Interference Ratio (SIR) and the sorting procedure for decoding/cancellation. So, due to complexity consideration, in the following we assume that at the R_g receiver the interfering signals are decoded with a fix sorting and given by the "natural" one, that is $f = 1, f = 2, \cdots, f = g-1, f = g+1, ..., f = n^\star$. Since this order is not adaptive, the conditions to guarantee $\mathcal{C} \equiv \mathcal{C}_0$ are expected to be more restrictive than those obtainable via an adaptive sorting. This drawback is counterbalanced by the reduction of complexity.

Assumption 8 *The decoding and subtraction order is given by the sequence*

$$f = 1, f = 2, \cdots, f = g-1, f = g+1, ..., f = n^\star, \forall g = 1, \cdots, n^\star. \tag{5}$$

Now, since no channel state information is available at the g-th transmitter ($g = 1, ..., n^\star$), the optimizing matrix $\mathbf{R}_{\varphi}$ is the isotropic unitary.

Assumption 9 *The covariance matrix for the signals $\underline{\varphi}^{(g)}(n)$ radiated by T_g is equal to the identity matrix.*

2.2. Information sent over the channels $T_g \rightarrow R_g$ and $T_f \rightarrow R_g$

Let us assume that the information rates $R(1), \cdots, R(f-1)$ corresponding to the $1, \cdots, f-1$ transmitters are less than the corresponding information throughput $\mathcal{I}(1, g), \cdots, \mathcal{I}(1, f-1)$ so to write

$$R(1) \leq \mathcal{I}(1, g) \text{ and } R(2) \leq \mathcal{I}(2, g) \text{ and } \cdots$$
$$\text{and } R(f-1) \leq \mathcal{I}(f-1, g) \tag{6}$$

so the sequences $\left\{\underline{\varphi}^{(1)}(n)\right\}, \cdots, \left\{\underline{\varphi}^{(f-1)}(n)\right\}$ can be decoded so we can consider that the corresponding estimates $\{\underline{\hat{\varphi}}^{(1)}(n)\}, \cdots, \{\underline{\hat{\varphi}}^{(f-1)}(n)\}$ obtained from the first $(f-1)$ block of the receiver are *exact* so to write

$$\underline{\hat{\varphi}}^{(i)}(n) \equiv \underline{\varphi}^{(i)}(n), \forall i = 1, \cdots, f-1 \tag{7}$$

and consequently we have that the signal at the input of the f-th estimator/canceler block is given by the following relationship:

$$\underline{\mathbf{y}}_f^{(g)}(n) \equiv \frac{\mathbf{H}^{(g,g)^T}\underline{\varphi}^{(g)}(n)}{\sqrt{t_g(l(g,g))^{\beta}}} + \sum_{\substack{i=f \\ f \neq g}}^{n^\star} \frac{\mathbf{H}^{(i,g)^T}\underline{\varphi}^{(i)}(n)}{\sqrt{t_i(l(i,g))^{\beta}}} + \underline{\mathbf{w}}^{(g)}(n) \equiv$$

$$\frac{\mathbf{H}^{(f,g)^T}\underline{\varphi}^{(f)}(n)}{\sqrt{t_f(l(f,g))^{\beta}}} + \sum_{\substack{i=f+1 \\ f \neq g}}^{n^\star} \frac{\mathbf{H}^{(i,g)^T}\underline{\varphi}^{(i)}(n)}{\sqrt{t_i(l(i,g))^{\beta}}} + \frac{\mathbf{H}^{(g,g)^T}\underline{\varphi}^{(g)}(n)}{\sqrt{t_g(l(g,g))^{\beta}}} + \underline{\mathbf{w}}^{(g)}(n) \tag{8}$$

this implies that $\mathcal{I}(f, g)$ in (6) is the mutual information having as input $\underline{\varphi}^{(f)}(n)$ and as output $\underline{\mathbf{y}}_f^{(g)}(n)$.

This last can be evaluated under the requirement that all the above reported 9 Assumptions hold in the following way

$$\mathcal{I}(f, g) \equiv \text{E}\left\{\ln\det\left[\mathbf{I}_{r_g} + \frac{P^{(g)}}{t_f\left(l(f,g)\right)^{\beta}}\mathbf{H}^{(f,g)^{\dagger}}\mathbf{H}^{(f,g)} \times \right.\right.$$
$$\times\left(\mathcal{N}_0^{(g)}\mathbf{I}_{r_g} + \frac{P^{(g)}}{t_g\left(l(g,g)\right)^{\beta}}\mathbf{H}^{(g,g)^{\dagger}}\mathbf{H}^{(g,g)} + \right.$$
$$\left.\left.\left.\sum_{\substack{i=f+1 \\ f \neq g}}^{n^\star} \frac{P^{(i)}}{t_i\left(l(i,g)\right)^{\beta}}\mathbf{H}^{(i,g)^{\dagger}}\mathbf{H}^{(i,g)}\right)^{-1}\right]\right\} \tag{9}$$

and when $t_1 \rightarrow \infty, \cdots, t_{n^\star} \rightarrow \infty$ we have that

$$\lim_{\substack{t_1 \rightarrow \infty \\ \cdots \\ t_{n^\star} \rightarrow \infty}} \mathcal{I}(f, g) \equiv r_g \ln\left[1 + \left(\frac{l(g,g)}{l(f,g)}\right)^{\beta}\right.$$

$$\left. \frac{P^{(f)}}{P^{(g)} + \mathcal{N}_0^{(g)} l(g,g)^{\beta} + \sum_{\substack{i=f+1 \\ i\neq g}}^{n^\star} \frac{P^{(i)}(l(g,g))^{\beta}}{(l(i,g)^{\beta})}} \right] . \quad (10)$$

Proposition 1 *Sufficient and necessary conditions allowing $\mathcal{C} \equiv \mathcal{C}_0$ is that the following $n^\star(n^\star - 1)$ inequalities simultaneously hold*

$$\mathcal{I}(g,k) \geq C^{(g)},\ k = 1, \cdots, n^\star,\ k \neq g,\ g = 1, \cdots, n^\star \quad (11)$$

Proof: The Shannon channel coding theorem [4] assures that $\hat{\underline{\varphi}}^{(g)}(n) = \underline{\varphi}^{(g)}(n)$ if and only if $R(1) \leq \mathcal{I}(1,g)$, $\cdots, R(g-1) \leq \mathcal{I}(g-1,g), R(g+1) \leq \mathcal{I}(g+1,g), \cdots$, $R(n^\star) \leq \mathcal{I}(n^\star, g), R(g) \leq C^{(g)}$ that can be rewritten as (by assuming $f \neq g$)

$$\hat{\underline{\varphi}}^{(g)}(n) \equiv \underline{\varphi}^{(g)}(n) \Longleftrightarrow R(g) \leq C^{(g)} \text{ and } R(f) \leq \mathcal{I}(f,g) \quad (12)$$

The relationship in (12) is referred to the g-th receiver but this implies that it has to hold for each value of $g = 1, ..., n^\star$ that is equivalent to affirm that all the receivers correctly estimate and decode the interfering and desired signals. Hence the condition allowing a perfect decoding can be described as

$$\hat{\underline{\varphi}}^{(g)}(n) \equiv \underline{\varphi}^{(g)}(n)\ \ \forall g = 1, ..., n^\star \rightleftarrows$$

$$\rightleftarrows R(g) \leq \min\{C^{(g)}, \mathcal{I}(g,k), k = 1, ..., n^\star,\ k \neq g\} \quad (13)$$

Now, since $C^{(g)} \geq \mathcal{I}(g,k), \forall k \neq g$, from (13) follows that if we want $\mathcal{C} \equiv \mathcal{C}_0$ we have to impose that $\forall g = 1, ..., n^\star$ the following $(n^\star - 1)$ inequalities hold

$$\mathcal{I}(g,k) \geq C^{(g)}, k = 1, ..., n^\star,\ k \neq g \quad (14)$$

and so we obtain (11). ■

The goal is to derive conditions on distances between nodes. Let us begin with considering the simple limit case when the 9 Assumptions hold and $t \to \infty$, $g = 1, ..., n^\star$. Under the above hypotheses the sufficient and necessary condition to obtain $\mathcal{C} \equiv \mathcal{C}_0$ is that all the following $n^\star(n^\star - 1)$ inequalities hold

$$l(g,k) \leq \left[\frac{P^{(g)}}{\left(1 + \frac{P^{(g)}}{\mathcal{N}_0^{(g)}(l(g,g))^{\beta}}\right)^{r_g/r_k} - 1} \right]^{1/\beta} \cdot$$

$$\cdot \left[\mathcal{N}_0^{(k)} + \frac{P^{(k)}}{(l(k,k))^{\beta}} + \sum_{\substack{i=g+1 \\ i\neq k}}^{n^\star} \frac{P^{(i)}}{(l(i,k))^{\beta}} \right]^{-1/\beta},$$

$$k = 1, ..., n^\star,\ k \neq g, g = 1, ..., n^\star. \quad (15)$$

The proof is not reported, it is sufficient to apply eq. (10) to (11). Since the summation in (15) depends on distances between the nodes $g+1, ..., n^\star$ and the k-th one, the limits have to be calculated from the $n^\star - th$ to the first ($g = n^\star$ as the first and $g = 1$ as the last). Once analyzed this particular case it is more interesting to consider the case of $t_g < \infty$, $g = 1, ..., n^\star$.

2.3. Bounding on Capacity

By applying the Jensen inequality we have that

$$C^{(g)} \leq r_g \ln\left(1 + \frac{P^{(g)}}{\mathcal{N}_0^{(g)}(l(g,g))^{\beta}}\right), g = 1, \cdots, n^\star \quad (16)$$

where the equality hold if $t_g \to \infty$.

Once supposed that the 9 Assumptions hold for each pair composed by f-th transmitter and g-th receiver we have that

$$\mathcal{I}(f,g) \geq \ln\left(1 + P^{(f)} r_g (l(g,g))^{-\beta} \left[\mathcal{N}_0^{(g)} + \frac{P^{(g)}}{(l(g,g))^{\beta}} + \sum_{\substack{i=f+1, \\ f\neq g}}^{n^\star} \frac{P^{(i)}}{(l(i,g))^{\beta}}\right]^{-1}\right),\ f \neq g,\ 1 \leq f, g \leq n^\star. \quad (17)$$

The proof is based on the "pessimistic hypothesis" of Key-Hole[1] channel [6]. By considering (11), (16) and (17) we obtain the following bound on $l(g,k)$ that has to be numerically evaluated starting from $g = n^\star$ as for (15) and it is given by

$$l(g,k) \leq \left[\frac{r_k P^{(g)}}{\left(1 + \frac{P^{(g)}}{\mathcal{N}_0^{(g)}(l(g,g))^{\beta}}\right)^{r_g} - 1} \right]^{1/\beta} \cdot$$

$$\cdot \left[\mathcal{N}_0^{(g)} + \frac{P^{(k)}}{(l(k,k))^{\beta}} + \sum_{i=g+1, i\neq k}^{n^\star} \frac{P^{(i)}}{(l(i,k))^{\beta}} \right]^{-1/\beta}. \quad (18)$$

In (18) the term $t_g, g = 1, ..., n^\star$ is not present and this is a consequence of the key-hole assumption that implies the loss of transmission diversity. As an application scenario we consider a *homogeneous network* where all the users present the same power levels, noise levels, number of antennas and distances. In brief we can pose $P^{(1)} = \cdots = P^{(n^\star)} = P$, $\mathcal{N}_0^{(1)} = \cdots = \mathcal{N}_0^{(n^\star)} = \mathcal{N}_0$, $r_1 = \cdots = r_{n^\star} = r$, $l(1,1) = ... = l(n^\star, n^\star) = 1$.

By introducing the following variables

$$\alpha \triangleq \left[\frac{r}{\left(1 + \frac{P}{\mathcal{N}_0}\right)^r - 1} \right]^{1/\beta} \quad (19)$$

[1]For more details see [7,8].

and

$$A(g) \triangleq \frac{\alpha}{\left\{1 + \frac{\mathcal{N}_0}{P} + \sum_{i=g+1}^{n^\star} \left(\frac{1}{A(i)}\right)^{\beta}\right\}^{1/\beta}} \qquad (20)$$

we can arrive at the following result.

By considering as verified the conditions about homogeneous network and the 9 Assumptions, sufficient conditions allowing $\mathcal{C} \equiv \mathcal{C}_0$ are that

$$l(g,k) \leq \begin{cases} A(g+1), \ \forall k = g+1, \cdots, n^\star \\ A(g), \ \forall k = 1, \cdots, g \end{cases} \qquad (21)$$

Under the hypotheses of homogenous network the (18) becomes

$$l(g,k) \leq \alpha \left\{ 1 + \frac{\mathcal{N}_0}{P} + \sum_{i=g+1}^{n^\star} (l(i,k))^{-\beta} \right\}^{-1/\beta},$$

$$1 \leq k \leq n^\star, \, k \neq g \qquad (22)$$

As important properties of $A(g)$ it derives that

$$0 \leq A(g) < 1, \ \forall g = 1, \cdots, n^\star \qquad (23)$$

$$0 \leq A(1) < A(2) < \cdots < A(n^\star) < 1 \qquad (24)$$

that is the sequence is increasing and bounded in the interval $[0, 1)$.

The last result to check is to evaluate what happens when the number of nodes approaches infinity.

Let us consider as verified all the Assumptions and the hypotheses for homogeneous network, if $n^\star \to \infty$ the limits in (21) approaches zero when $g \to 1$. The proof consist into noting that the summation in (20) is composed by infinite terms greater then unity so we have $A(g) \to \infty$.

Two are the main implications of this last result. The first one is that in order to have $\mathcal{C} \equiv \mathcal{C}_0$, when $n^\star \to \infty$, the users have to be very close each other.

The second one is that if the number of users increases, this does not reduce the capacity (because the conditions require $\mathcal{C} \equiv \mathcal{C}_0$) so, in contrast with the result in [3] about multi-hop, the capacity does not fall to zero.

Remark 1. (About the impact of the above analysis on routing: multi-hop vs. single-hop). About *multi-hop-routing*, it is well know that in this context each receiver has to decode information received by the corresponding transmitter and the signals received from other users is considered as additional noise.

About the receiver architecture we can observe that

a) The interference experienced by the receiver *reduce* the capacity region and the reduction is proportional to the loss of Signal-to-interference Ratio (SIR);

b) In order to have low SIR, the interference level has to be low and this implies that low power has to be emitted;

c) Since the coverage area of each transmit node is poor, we need relays (multi-hop routing) in order to reach the destination receiver;

d) This approach presents the following two drawbacks:

- More than one node has to transmit information so it cannot send its packets but it has to relay. As a consequence the aggregate throughput falls to zero when the number of users increases [3];
- This technique increases the packet delivery time.

When we consider a *single-hop* strategy, the conclusions made in a),b),c) and d) changes. In fact we have that

α) The interference does not reduce the capacity region ($\mathcal{C} \equiv \mathcal{C}_0$) with respect of interference-free channel;

β) Since conditions in (17), (18) require that the distances between nodes of links $T_g \to R_g$ are greater than the ones on interferers $T_f \to R_g$ no reasons make multi-hop an appealing strategy. In fact, by adopting single-hop strategy we have that

- when (17), (18) hold the capacity region is the same of an interference-free channel ($\mathcal{C} \equiv \mathcal{C}_0$)
- the network throughput does not falls to zero when the number of users increases because no relays are present.

3. NUMERICAL RESULTS AND CONCLUSIONS

In Fig.1 the bounds in (16) and (17) are presented for testing the behavior of $C^{(g)}$ and $\mathcal{I}(f,g)$ with respect to distances. The comparisons between bounds are performed for different values of receive antennas ranging from 1 to 8 and distances $l(1,1), l(2,2)$ ranging from 1 to 20 meters. The

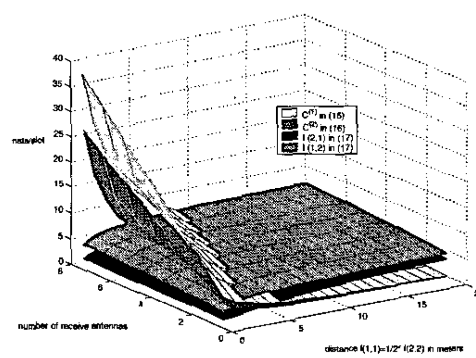

Fig. 1. Direct and interference link capacity for different values of r and $l(1,1), l(2,2)$.

ratio $\frac{P^{(g)}}{\mathcal{N}_0^{(g)}}$ is set to 20dB while $l(2,1) = 1mt, l(1,2) = 3mt, l(2,2) = 2l(1,1)$ and $\beta = 2$. It is possible to note that, since $l(1,2)$ and $l(2,1)$ are assigned, when $l(1,1)$ and $l(2,2)$ present low values, $C^{(g)}$ and $\mathcal{I}(f,g)$, $1 \leq f, g \leq$

2 do not verify the eq. (11) (this means that $l(1,2)$ and $l(2,1)$ do not verify (18), while, when $l(1,1)$ and $l(2,2)$ increase, the eq.(11) hold and (18) too. So, by increasing the number of antennas ($r_1 = r_2$) the distance limit, allowing that (11) and (18) hold, increases. This means that when $r_1 = r_2 = 3$ if $l(1,1) = \frac{1}{2}l(2,2) \geq 5mt$ the (11) hold so $\mathcal{C} \equiv \mathcal{C}_0$ while when $r_1 = r_2 = 8$, in order to verify (11) and so $\mathcal{C} \equiv \mathcal{C}_0$, we have to require that $l(1,1) = \frac{1}{2}l(2,2) \geq 9mt$. In Fig.2 a different situation is presented. In this case the distances $l(1,1)$ and $l(2,2)$ are assigned ($l(1,1) = 10mt$ and $l(2,2) = 16mt$) while the interfering distances $l(1,2) = \frac{1}{2}l(2,1)$ range from 1 to 20 meters. As in the previous case $r_1 = r_2$ range from 1 to 8 and $\frac{P^{(g)}}{\mathcal{N}_0^{(g)}} = 20dB$. By considering different values of $r_1 = r_2$, when $r_1 = r_2$ present low values the distance limits $l(1,2) = \frac{1}{2}l(2,1)$ verifying (11) approaches 16-18 meters, while when the number of receive antennas increases then the distance limits decrease full to few meters. Last in Fig.3 by considering a topology with $l(1,1) = 10, l(2,2) = 16mt$ and $l(1,2) = \sqrt{(l(2,2) - l(1,1))^2 - l(2,1)^2}$ (this means trapezoidal topology with variable value of $l(2,1)$) the interference cancellation capabilities for different values of distances are represented by considering different number of receive antennas.

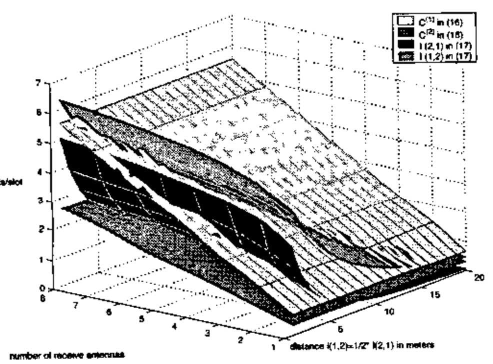

Fig. 2. Direct and interference link capacity for different values of r and $l(1,2), l(2,1)$.

The external circle (in black) is the coverage interference cancellation area (CICA) when $r_1 = 8$, that means that if the receiver 1 is equipped with $r_1 = 8$ antennas and it is in that area it is possible for it to cancel interference. On the other hand the internal circle is the one representing the CICA when $r_1 = 1$. The evaluation is performed by assuming $\frac{P^{(g)}}{\mathcal{N}_0^{(g)}} = 20dB$ and $\beta = 2$. The conclusions that may be carried out are the following. First, the impact of topology on capacity is very important as already show in [1] and it is due to the different levels on interference. So the conditions allowing perfect interference cancellation

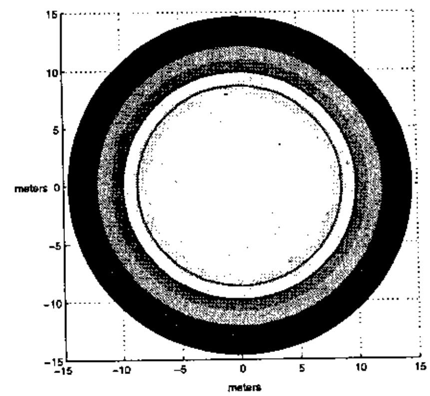

Fig. 3. Maximum coverage interference cancellation area (CICA) by considering r ranging from 8 to 1.

are given for two pairs of transmit/receive nodes. Second, the impact of the conditions on capacity are considered via distance limits inequalities. Last, the particular case of homogeneous network is considered and the impact of interference cancellation on routing strategies as discussed by showing advantages and drawbacks both of multi-hop and single-hop approaches.

4. REFERENCES

[1] E.Baccarelli, M.Biagi, C.Pelizzoni, G.Razzano, "Contracted QoS policies for Distributed Space Division Multiple Access for "ad-hoc" Networks", QSHINE04, pp.36-43, Oct.2004.

[2] A.Carleial, "A case where interference does not reduce capacity", IEEE Trans. on Inf. Theory, Vol. 21, no.5, pp.569-570, Sept. 1975.

[3] P.Gupta, P.R.Kumar, "The capacity of wireless networks", IEEE Trans. on Inf. Theory, Vol. 46, no.2, pp.388-404, March2000.

[4] T.M.Cover, J.A.Thomas, "Elements of Information Theory", John Wiley, 1991.

[5] S.Verdu, Multiuser Detection, Cambridge Univ. Press, 1988.

[6] A. Paulraj, R. Nabar and D. Gore, Introduction to Space-Time Wireless Communications, Cambridge Univ. Press, 2003

[7] M.Biagi, "Cross-Layer Optimization of Multi-Antenna 4G-WLANs", Ph.D. Dissertation, http://infocom.uniroma1.it/~biagi/phdthesis.html

[8] E.Baccarelli, M.Biagi, C.Pelizzoni, N.Cordeschi, "Multiple Access Interference Suppression and Capacity Regions of MIMO ad hoc networks: Towards a free interference channel", INFOCOM Tech. report, http://infocom.uniroma1.it/~biagi/mimoint.pdf