Opportunistic Use of Successive Interference Cancellation in Reverse TDD HetNets

Rakesh Gorrepati, Sachin Chaudhari, and Taneli Riihonen

***Abstract*—Cross-tier interference management is one of the major challenges in heterogeneous cellular networks (HetNets). Though the network throughput increases due to a better area spectral efficiency of a HetNet, there is possibility that high interference will make few link capacities close to zero when users regard interference as noise (IAN). In this letter, successive interference cancellation (SIC) is used to cancel the cross-tier interference in a reverse time division duplexing (RTDD) scheme. We demonstrate that by opportunistic use of SIC, a minimum guarantee on the sum link capacity can be ensured for an RTDD HetNet. This minimum sum link capacity is later on proved to be the maximum that can be achieved by orthogonal resource allocation schemes. Through system-level simulations for random allocation, it is shown that the proposed scheme is better than using SIC and IAN alone. To further improve the overall system capacity, an optimization problem for selecting co-channel users is formulated, and the Hungarian algorithm is employed to solve it.**

***Index Terms*—HetNets, Hungarian algorithm, interference management, reverse TDD, resource allocation, SIC.**

I. Introduction

HETEROGENEOUS cellular networks (HetNets) are considered to be one of the key solutions to meet future wireless capacity needs. A two-tier HetNet consists of a high power macro base station (MBS) that provides wide-area coverage in a macrocell and a low-power small cell base station (SBS) to support local hotspot requirements. Severe interference problems may arise in the co-channel deployment of MBS and SBS, which is one of the main challenges in HetNets. A qualitative survey on the advanced interference management techniques for HetNets is presented in [1].

In [2], a novel reverse time division duplexing (RTDD) framework is proposed for a two-tier HetNet, which always operate in a synchronized fashion such that if the macro tier is in the uplink (UL), then the small tier will be in the downlink (DL) and vice-versa as shown in Fig. 1. This is motivated by the fact that the wired backhaul between the base stations (BSs) can now be exploited to eliminate the interference between MBS and SBS. In contrast to using wired backhaul, an interference alignment scheme is proposed in [3] to reduce the interference between base stations (BSs) of an RTDD HetNet having multiple antennas. The works in [2], [3] treat interference (between users) as noise (IAN). If proper scheduling is not done in this scenario, then interference between user equipments (UEs) could become very high and lead to meager data rates and may not ensure some minimum quality of service (QoS) to the UEs involved.

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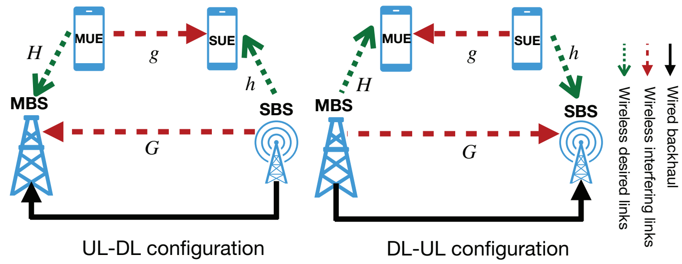

Fig. 1: Two possible configurations of a reverse TDD Hetnet.

To solve the QoS problem, we propose an opportunistic use of successive interference cancellation (SIC) that would ensure a minimum sum link capacity irrespective of the interference between the UEs. SIC receiver decodes the interfering signal and subtracts it from its received signal. In this paper, the sum link capacity achieved by a SIC receiver is derived and compared with the case of IAN. Based on the comparison, we propose opportunistic use of SIC (which is also referred to as *switching* in this paper). Another way of solving QoS problem is to allocate resources orthogonally. In this paper, we prove that the sum link capacity achieved by the proposed switching scheme is always greater than that of any orthogonal resource allocation schemes. Further, we consider a combinatorial optimization problem to pair the co-channel users in IAN, SIC and switching for a multi-user scenario and solve it with the Hungarian algorithm. Through system-level simulations, it is shown that the proposed scheme is better than using SIC and IAN alone for random as well as Hungarian pairing.

SIC has been used in HetNets [4] as well as in cognitive radio literature [5]. Also there have been works on interference-aware rate allocation in the literature [6], [7], where the problem is formulated as an optimization problem in multicell HetNet scenario and belief propagation among the BSs is used to solve it. The Hungarian algorithm has been used in [8] to manage the inter cell interference when the receivers treat IAN. However, unlike [4], [5], [6], [7], [8] our work concentrates on the opportunistic use of SIC in RTDD framework, which has not been considered before. Moreover, the Hungarian algorithm used in [8] is extended to the proposed switching scheme in our case and used in a intracell scenario where the number of MUEs, SUEs and RBs can be different.

II. System Model

Let us consider a two-tier RTDD HetNet, as shown in Fig. 1, where all the BSs and UEs have a single antenna. The MBS and SBS are assumed to be connected with a wired backhaul which is further connected to the core network. Configuration UL-DL and configuration DL-UL represent the operations of the MBS-SBS pair. Let $X_{\rm MBS}$ and $P_{\rm MBS}$ denote the transmission symbol and power of the MBS in one RB, such that $X_{\rm MBS} \sim \mathcal{CN}(0, \sqrt{P_{\rm MBS}})$. $Z_{\rm MBS}$ denotes the additive white Gaussian noise (AWGN) at the MBS with zero mean and σ^2 variance. Similar notations are also used for SBS, MUE, and SUE. The channel is modeled as a flat-fading Rayleigh channel within one RB. In Fig. 1, h, and H are the channel coefficients between (SBS, SUE) and (MBS, MUE), while g and G are the channel coefficients between (MUE, SUE) and (MBS, SBS), respectively. Each channel coefficient represents the effects of both path loss and small scale fading.

Let us assume that the transmissions across both the tiers are perfectly synchronized and all the UEs have SIC capabilities. In the UL-DL configuration of Fig. 1, both the MBS and the SUE will be in receiving mode. Let the symbols received at the MBS and SUE be denoted by $Y_{\rm MBS}$ and $Y_{\rm SUE}$, respectively. These can be modeled as

$$Y_{\rm MBS} = HX_{\rm MUE} + GX_{\rm SBS} + Z_{\rm MBS}\,, \tag{1}$$

$$Y_{\rm SUE} = hX_{\rm SBS} + gX_{\rm MUE} + Z_{\rm SUE}\,. \tag{2}$$

Consequently, the respective signal-to-interference-plus-noise ratios (SINRs) at MBS and SUE can be written as

$$\mathrm{SINR}^{\rm IAN}_{\rm MBS} = \frac{P_{\rm MUE}|H|^2}{P_{\rm SBS}|G|^2 + \sigma^2}, \tag{3}$$

$$\mathrm{SINR}^{\rm IAN}_{\rm SUE} = \frac{P_{\rm SBS}|h|^2}{P_{\rm MUE}|g|^2 + \sigma^2}, \tag{4}$$

where the noise variance σ^2 at all the nodes are assumed to be equal. By symmetry from Fig. 1, corresponding equations for the DL-UL configuration can be obtained by swapping H and h, MBS and SBS, MUE and SUE in the equations of the configuration A. Hence, equations are only derived for UL-DL configuration in this letter.

In any configuration, the transmitting BS shares its DL data via the wired backhual so that the other BS can reproduce the interfering signal and subtract it from its received signal [2]. In order to get accurate channel estimates of the desired and interfering links, all the pilots transmitted by the two transmitting nodes are assumed to be orthogonal. If the interference channel estimate between the BSs is ideal, then after exploiting the wired backhaul between BSs, as given in [2], (3) becomes

$$\mathrm{SNR}^{\rm IAN}_{\rm MBS} = \frac{P_{\rm MUE}|H|^2}{\sigma^2}. \tag{5}$$

Let B_o be the bandwidth of an RB. If $C^{\rm IAN}_{\rm MUE}$ denotes the maximum rate at which the MUE can transmit such that the MBS can decode, then this capacity can be written as

$$C^{\rm IAN}_{\rm MUE} = B_o \log_2\left(1 + \mathrm{SNR}^{\rm IAN}_{\rm MBS}\right). \tag{6}$$

From (4), the DL capacity is given by

$$C^{\rm IAN}_{\rm SBS} = B_o \log_2\left(1 + \mathrm{SINR}^{\rm IAN}_{\rm SUE}\right). \tag{7}$$

The sum link capacity achieved by the desired links of UL-DL configuration is given by summing (6) and (7)

$$C^{\rm IAN}_{\rm sum} = B_o \log_2\left[\left(1 + \mathrm{SINR}^{\rm IAN}_{\rm SUE}\right)\left(1 + \mathrm{SNR}^{\rm IAN}_{\rm MBS}\right)\right]. \tag{8}$$

III. Capacity Analysis for SIC Receivers

In this section, Shannon's capacity constraints are used to ensure that the interfering symbols between the UEs are decoded without any error during SIC. In the UL-DL configuration of Fig. 1, for the SUE to completely eliminate the cross-tier interference, it should decode all the data transmitted by the MUE. If we let $C^*_{\rm MUE}$ be the maximum rate at which the MUE can transmit so that the SUE can decode its data, then

$$\begin{aligned} C^*_{\rm MUE} &= B_o \log_2(1 + \text{SINR of MUE signal at SUE}) \\ &= B_o \log_2\left(1 + \frac{P_{\rm MUE}|g|^2}{P_{\rm SBS}|h|^2 + \sigma^2}\right). \end{aligned} \tag{9}$$

However, (6) gives the maximum rate at which the MUE can transmit so that MBS can decode its data. Let $C^{\rm SIC}_{\rm MUE}$ be the maximum data rate at which the MUE can transmit so that its data can be decoded both at the SUE and MBS:

$$C^{\rm SIC}_{\rm MUE} = \min\left\{C^*_{\rm MUE}, C^{\rm IAN}_{\rm MUE}\right\}. \tag{10}$$

Assume then that the MUE exploits the reciprocity of TDD systems and chooses its UL data rate such that the above equation is satisfied. Since the interference caused by the MUE can be removed by using SIC at the SUE, the term $P_{\rm MUE}|g|^2$ in (4) becomes zero and the SINR becomes $\mathrm{SNR}^{\rm SIC}_{\rm SUE} = P_{\rm SBS}|h|^2/\sigma^2$. Let $C^{\rm SIC}_{\rm SBS}$ denote the DL capacity of SBS after SIC so that

$$C^{\rm SIC}_{\rm SBS} = B_o \log_2\left(1 + \mathrm{SNR}^{\rm SIC}_{\rm SUE}\right). \tag{11}$$

Now, two different sum link capacity expressions are possible for SIC depending on which term in (10) is smaller.

Case I ($C^*_{\rm MUE} > C^{\rm IAN}_{\rm MUE}$): Substituting (6) and (9) in $C^{\rm IAN}_{\rm MUE}$ and $C^*_{\rm MUE}$, respectively, we get

$$B_o \log_2\left(1 + \frac{P_{\rm MUE}|g|^2}{P_{\rm SBS}|h|^2 + \sigma^2}\right) > B_o \log_2\left(1 + \frac{P_{\rm MUE}|H|^2}{\sigma^2}\right) \tag{12}$$

which simplifies to

$$|g|^2/|H|^2 > 1 + (P_{\rm SBS}|h|^2/\sigma^2). \tag{13}$$

Let us define $\mu = |g|^2/|H|^2$ and substitute $\mathrm{SNR}^{\rm SIC}_{\rm SUE}$ instead of $P_{\rm SBS}|h|^2/\sigma^2$,

$$\mu > 1 + \mathrm{SNR}^{\rm SIC}_{\rm SUE}\,, \tag{14}$$

In this case, (10) becomes $C^{\rm SIC}_{\rm MUE} = C^{\rm IAN}_{\rm MUE}$, so the maximum for MUE's transmission is given by (6). Summing (6) and (11), the sum link capacity for case I is

$$C^{\text{SIC-I}}_{\rm sum} = B_o \log_2\left[\left(1 + \mathrm{SNR}^{\rm IAN}_{\rm MBS}\right)\left(1 + \mathrm{SNR}^{\rm SIC}_{\rm SUE}\right)\right]. \tag{15}$$

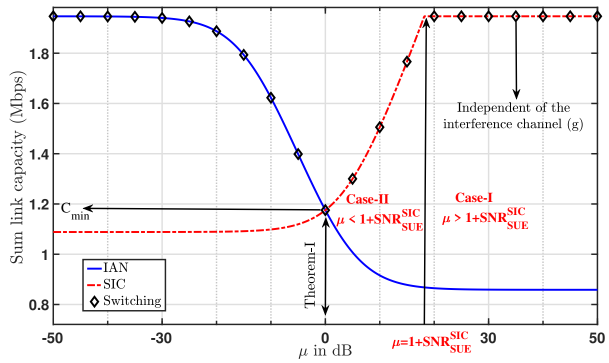

Fig. 2: Plot of sum link capacities of IAN and SIC in terms of μ for fixed $|H|^2$ and $|h|^2$, while varying $|g|^2$.

Case II $C^{*}_{\text{MUE}} < C^{\text{IAN}}_{\text{MUE}}$ or $\mu < 1 + \text{SNR}^{\text{SIC}}_{\text{SUE}}$: We know from (10) that the maximum rate at which the MUE can transmit is given by (9). So the sum link capacity that can be achieved in case II is expressed by adding (9) and (11) as

$$\begin{aligned} C^{\text{SIC-II}}_{\text{sum}} =& B_o \log_2 \left[\left(1 + \frac{P_{\text{MUE}}|g|^2}{P_{\text{SBS}}|h|^2 + \sigma^2}\right)\left(1 + \frac{P_{\text{SBS}}|h|^2}{\sigma^2}\right)\right] \\ =& B_o \log_2 \left(1 + \frac{P_{\text{MUE}}|g|^2 + P_{\text{SBS}}|h|^2}{\sigma^2}\right). \end{aligned} \tag{16}$$

IV. Switching Between SIC and IAN

In this section, the sum link capacities of IAN and SIC are compared, and a switching condition between them is derived.

Theorem 1. *In an RTDD HetNet, using SIC gives better sum link capacity than IAN if and only if $\mu > 1$ and vice-versa.*

Proof. The sum link capacities of IAN and SIC are given by (8) and (16), respectively. Eq. (8) can be further written as

$$C^{\text{IAN}}_{\text{sum}} = B_o \log_2 \left[1 + \frac{P_{\text{MUE}}|H|^2}{\sigma^2} + \frac{P_{\text{SBS}}|h|^2}{\sigma^2}\left(\frac{P_{\text{MUE}}|H|^2 + \sigma^2}{P_{\text{MUE}}|g|^2 + \sigma^2}\right)\right] \tag{17}$$

If $C^{\text{SIC-II}}_{\text{sum}} > C^{\text{IAN}}_{\text{sum}}$, then the terms inside the log will also follow the same inequality condition as log is a monotonic function. After some simplifications,

$$\frac{P_{\text{SBS}}|h|^2}{\sigma^2}\left(1 - \frac{P_{\text{MUE}}|H|^2 + \sigma^2}{P_{\text{MUE}}|g|^2 + \sigma^2}\right) > \frac{P_{\text{MUE}}(|H|^2) - |g|^2)}{\sigma^2} \tag{18}$$

$$\frac{P_{\text{SBS}}|h|^2}{\sigma^2}\left(\frac{P_{\text{MUE}}(|g|^2 - |H|^2)}{P_{\text{MUE}}|g|^2 + \sigma^2}\right) > \frac{P_{\text{MUE}}(|H|^2) - |g|^2)}{\sigma^2}. \tag{19}$$

Canceling P_{MUE} and σ^2 terms on both sides and rearranging,

$$P_{\text{SBS}}|h|^2\left(\frac{(|g|^2 - |H|^2)}{P_{\text{MUE}}|g|^2 + \sigma^2}\right) + (|g|^2 - |H|^2) > 0 \tag{20}$$

$$(|g|^2 - |H|^2)\left(\frac{P_{\text{SBS}}|h|^2}{P_{\text{MUE}}|g|^2 + \sigma^2} + 1\right) > 0. \tag{21}$$

The only way the above condition gets satisfied is when $|g|^2 > |H|^2$ or $\mu > 1$. If $\mu > 1 + \text{SNR}^{\text{SIC}}_{\text{SUE}}$, then (15) gives the rate achieved by SIC which is always greater than (8). □

Figure 2 illustrates the theorem by plotting the sum link capacities of IAN and SIC for different values of μ. Treating IAN could make (7) converge to zero for high $|g|^2$ while using SIC could make (9) converge to zero for low $|g|^2$. Although careful scheduling can be done to keep the undesired g values in check, this requires substantial channel state information regarding cross-tier channels. Both IAN and SIC curves meet at $\mu = 1$, which is the minimum sum link capacity C_{min} that is ensured when the derived switching condition is used. This C_{min} is given by substituting $|H|^2$ for $|g|^2$ in (8) or (16) as

$$C^{\text{switch}}_{\text{min}} = B_o \log_2 \left(1 + \frac{P_{\text{MUE}}|H|^2 + P_{\text{SBS}}|h|^2}{\sigma^2}\right). \tag{22}$$

The independence of C_{min} on $|g|^2$ makes it desirable in terms of ensuring some non-zero rate in UL and DL even if the scheduler randomly allocates RBs. In any configuration, the value of μ is assumed to be know to the scheduler and there by it allocates the corresponding rates based on the switching condition.

V. Superiority of Switching Compared to Orthogonal Resource Allocation

In this section, we will compare and show that switching always performs better than any other orthogonal resource allocation scheme. Let us assume f fraction of RB's bandwidth is given to one MUE and $(1 - f)$ fraction of it is given to one SUE. We know that the noise variance at any node is proportional to the bandwidth of the signal that is received. Hence, the noise variance at MUE and SBS will be $f\sigma^2$ and $(1 - f)\sigma^2$ since σ^2 is the noise variance for B_o bandwidth.

$$C^{\text{orth}}_{\text{MUE}} = f B_o \log_2 \left(1 + \frac{P_{\text{MUE}}|H|^2}{f\sigma^2}\right), \tag{23}$$

$$C^{\text{orth}}_{\text{SBS}} = (1 - f) B_o \log_2 \left(1 + \frac{P_{\text{SBS}}|h|^2}{(1 - f)\sigma^2}\right). \tag{24}$$

The terms $P_{\text{MUE}}|H|^2/\sigma^2$ and $P_{\text{SBS}}|h|^2/\sigma^2$ in (23) and (24) are replaced by SNR_{MBS} and SNR_{SUE} respectively, and both the equations are added to get the sum link capacity as

$$C^{\text{orth}}_{\text{sum}} = C^{\text{orth}}_{\text{MUE}} + C^{\text{orth}}_{\text{SBS}}. \tag{25}$$

To find the maxima/minima of $C^{\text{orth}}_{\text{sum}}$, let us differentiate it by f and equate it to zero.

$$C^{\text{orth}'}_{\text{sum}} = C^{\text{orth}'}_{\text{MUE}} + C^{\text{orth}'}_{\text{SBS}} = 0, \tag{26}$$

where $C^{\text{orth}'}_{\text{MUE}}$ and $C^{\text{orth}'}_{\text{SBS}}$ can be obtained by differentiating (23) and (24), respectively as

$$C^{\text{orth}'}_{\text{MUE}} = B_o \log_2 \left(1 + \frac{\text{SNR}_{\text{MBS}}}{f}\right) - \frac{B_o}{\left(\frac{f}{\text{SNR}_{\text{MBS}}} + 1\right)\ln 2}, \tag{27}$$

$$C^{\text{orth}'}_{\text{SBS}} = -B_o \log_2 \left(1 + \frac{\text{SNR}_{\text{SUE}}}{(1 - f)}\right) + \frac{B_o}{\left(\frac{(1 - f)}{\text{SNR}_{\text{SUE}}} + 1\right)\ln 2}. \tag{28}$$

Let $f = f_o$ be the local maxima/minima which can be obtained by equating $\text{SNR}_{\text{MBS}}/f$ and $\text{SNR}_{\text{SUE}}/(1-f)$ since this cancels the corresponding first and second terms of (27) and (28)

$$\frac{\text{SNR}_{\text{MBS}}}{f_o} = \frac{\text{SNR}_{\text{SUE}}}{1 - f_o}, \tag{29}$$

Substituting $P_{\text{MUE}}|H|^2/\sigma^2$ and $P_{\text{SBS}}|h|^2/\sigma^2$ in place of SNR_{MBS} and SNR_{SUE} in (29) respectively, and solving for f_o leads to

$$f_o = \frac{P_{\text{MUE}}|H|^2}{P_{\text{MUE}}|H|^2 + P_{\text{SBS}}|h|^2}. \tag{30}$$

The double derivative at $f = f_o$ is computed and has been verified to be negative. Substituting the above value of f_o for f in the equation (25) and further simplifying it leads to

$$C^{\text{orth}}_{\max} = B_o \log_2\left(1 + \frac{P_{\text{MUE}}|H|^2 + P_{\text{SBS}}|h|^2}{\sigma^2}\right). \tag{31}$$

The expressions for $C^{\text{orth}}_{\text{MUE}}$ and $C^{\text{orth}}_{\text{SUE}}$ will remain the same even when the time slot is partitioned between the UEs of a (MUE, SUE) pair. Here (22), which is the minimum capacity that is ensured when switching is used, is the same as (31), which is the maximum capacity that can be achieved if the resources are split across the tiers. Hence switching would always give a better performance than allocating resources orthogonally across the tiers for our system model.

VI. Hungarian Pairing

Till now, only a pair of MBS-MUE and SBS-SUE have been considered for the sum link capacity analysis. In this section, a resource allocation algorithm is employed for the scenario, where the system contains multiple MUEs and SUEs. Let us assume that M MUEs, S SUEs and R RBs are present in our RTDD HetNet. Since more than R UEs cannot be accommodated in any tier, both M and S should be less than R. The maximum number of UEs that can be accommodated for the given system model is always less than $2R$. This condition can be represented by the equation $M + S < 2R$. Let k be the number of (MUE, SUE) pairs that need to be formed so that all the MUEs and SUEs are allocated with some RB. All the MUEs and SUEs which are not paired with each other will be given one RB. Hence the total number of RBs is equal to the sum of unpaired MUEs, unpaired SUEs and number of (MUE, SUE) pairs.

$$M - k + S - k + k = R. \tag{32}$$

Hence the number of (MUE, SUE) pairs that needs to be formed is $k = M + S - R$.

From Fig. 2, it is clear that the sum link capacity of IAN, SIC and switching for an (MUE, SUE) pair depends on the cross-tier channel strength $|g|^2$ for a fixed $|H|^2$ and $|h|^2$. This, in turn, depends on the distance between the UEs and the RB allocated. So if the scheduler has the necessary information regarding the desired and interfering channels, it can schedule those MUEs and SUEs to be in some identical RBs such that the overall system capacity is maximum. However, the joint maximization of system capacity with RB allocation is NP-complete [9]. Hence, a sub-optimal pairing algorithm is considered with random RB allocation that solves the pairing between MUEs and SUEs, which should get the same RB. Since only k pairs needs to be formed, this can be thought of as which set of MUEs and SUEs should be paired (giving same RB to MUE and SUE) and what should be the pairing between them. To get this pairing, only path loss terms at the carrier frequency are considered in the channels coefficients while computing the sum link capacities.

An $M \times S$ matrix is constructed such that the element $\boldsymbol{O}(i, j)$ contains the sum link capacities when ith MUE and jth SUE are given distinct RBs ($|g|^2 = 0$). Another $M \times S$ matrix is constructed such that the element $\boldsymbol{C}(i, j)$ contains the sum link capacities when ith MUE and jth SUE are given same RBs. We want to pair k MUEs and SUEs for which there is minimum loss in the sum link capacity after giving the same RB. The loss in the sum link capacity for each pair can be given by subtracting $\boldsymbol{C}$ from $\boldsymbol{O}$. Let the matrix $\boldsymbol{E}$ denote the this loss in sum link capacity and hence $\boldsymbol{E} = \boldsymbol{O} - \boldsymbol{C}$. Now k elements are to be selected from this matrix such that no two of them are from the same row or column, and their sum is minimized. This assignment problem can be formulated as

$$\begin{aligned} &\min_{x_{i,j}} \sum_{i=1}^{M}\sum_{j=1}^{S} x_{i,j}\boldsymbol{E}(i, j), \quad x_{i,j} \in \{0, 1\}, \\ &\text{s.t.} \ \sum_{i=1}^{M} x_{i,j} \le 1, \quad \sum_{j=1}^{S} x_{i,j} \le 1, \quad \sum_{i=1}^{M}\sum_{j=1}^{S} x_{i,j} = k. \end{aligned} \tag{33}$$

The above optimization problem is a *k-cardinality* assignment task and can be solved using the Hungarian algorithm with some preprocessing done on the cost matrix ($\boldsymbol{E}$) [10]. For a $N \times N$ square matrix, the run time complexity of the Hungarian algorithm is $O(N^3)$. In our case, we have a $M \times S$ rectangular matrix, and one can make it into a square matrix of order max(M,S) $\times$ max(M,S). The solution for this depends on whether the receiver uses IAN, SIC, or switching since the sum link capacity expressions in $\boldsymbol{C}$ will change for each one of them. This is better than randomly pairing MUEs and SUEs (random allocation). In both random and Hungarian allocations, once the pairing is done, RBs are randomly allocated across the selected pairs of (MUE, SUE). Let the resulting sum link capacity of the pth pair with small scale fading be denoted by $C_{\text{sum}}(p)$ while the system capacity is computed by adding all the elements of C_{sum} and the orthogonal rates of the unpaired MUE/SUEs.

VII. Simulation Results

Let us consider a circular macrocell of radius R, where the MBS is placed at the center and the SBSs (pico-cell BSs) are placed randomly inside the circle. Generally, the coverage radius of a small cell in a two-tier HetNet is proportional to its distance from MBS as discussed in [11]. Thus, effective use of picocells cannot be achieved if they are deployed near MBS as it will reduce their coverage area. So the pico-cells are randomly placed between the concentric circles of radius $0.5R$ to $0.9R$ such that their coverage areas do not overlap. Once the coverage radius of each of the SBS is computed, SUEs are randomly placed in its coverage area. The same number of MUEs are placed in the macrocell such that they lie outside any SBS's coverage area. We consider 1000 such deployments while pairing between MUEs and SUEs is computed only once per deployment. For each deployment, 1000 realizations of the small-scale fading are considered. All the other relevant

TABLE I: Simulation Parameters

MBS Tx power	46 dBm	
SBS (Pico) Tx power	30 dBm	
Antenna gain	Macro	14 dBi
	Pico	5 dBi
MUE and SUE Tx power	23 dBm	
Carrier frequency	2.1 GHz	
Path loss exponent	3	
Small scale fading	Rayleigh	
Noise power spectral density	-174 dBm/Hz	
BW of RB (B_o)	180 kHz	
No. of MUEs + No. of SUEs	30 + 28	
No. of SBSs × No. of SUEs per SBS	4 × 7	
Radius of macrocell (R)	150 m	

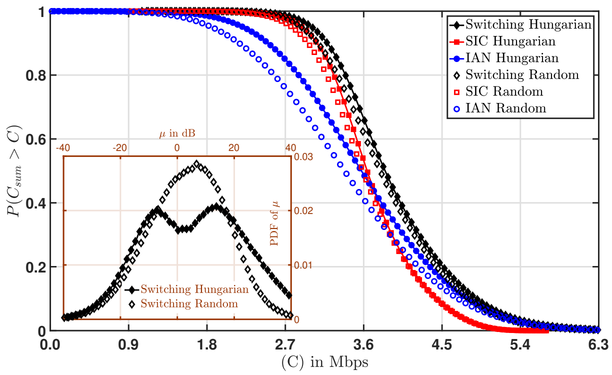

Fig. 3: CCDFs of C_{sum} for IAN, SIC and switching in random and Hungarian pairing at a sector angle of 40°. The inset figure shows the PDF of μ values when switching is used in the UL-DL configuration.

simulation parameters are listed in Table I, and most of them were taken from [12].

In Fig. 3, the complementary cumulative distribution functions (CCDFs) of C_{sum} in random and Hungarian pairing for IAN, SIC and switching are shown when exactly 30 RBs are present in the system. The absolute increase in the CCDF of switching w.r.t. IAN and SIC show the QoS improvement. The CCDFs of IAN, SIC and switching for Hungarian pairing are better than their random counterparts while switching in Hungarian dominates all of them. The inset-figure in Fig. 3 gives the probability distribution of the selected μ values for switching with random and Hungarian pairing. Notice the drop at $\mu = 1$ for Hungarian pairing, which is where the minimum sum link capacity is achieved when switching is used.

Fig. 4, plots the total system throughput of IAN, SIC and switching with both random and Hungarian pairing for a sector angle of 40°. Results for this sector angle are given to consider the scenario where the user density is very high and one wants to reuse the frequency with in a smaller sector angle by forming narrower beams. Note that switching has better system throughput than IAN and SIC for both the pairing algorithms. Also the system throughput of IAN, SIC and switching for Hungarian pairing are better than their random counterparts. The number of RBs is varied from 30 to 58, which makes the number of unpaired MUEs and SUEs increase as RBs increase. For 58 RBs all the 30 MUEs and 28 SUEs will be given orthogonal RBs and the interference between UEs becomes zero ($|g|^2 = 0$). Hence IAN, SIC or switching for random or Hungarian pairing will be same.

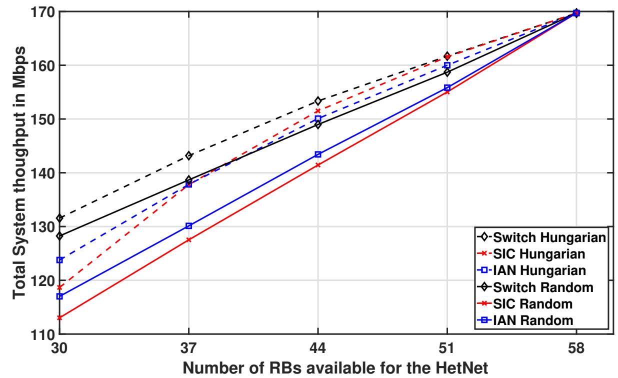

Fig. 4: The total system throughput of IAN, SIC and switching in random and Hungarian pairing at a sector angle of 40° for UL-DL configuration.

VIII. Conclusion

The sum link capacities of SIC and IAN are derived and compared to get a switching condition that always chooses the better one. This opportunistic use of SIC ensures a minimum guarantee on sum link capacity, which is proved to be the maximum that can be achieved by any orthogonal resource allocation schemes. A sub-optimal resource allocation problem is formulated, and the Hungarian algorithm is used to solve it for IAN, SIC, and switching with a different number of MUE, SUEs, and RBs. The opportunistic use of SIC along with the proposed Hungarian pairing is shown to give a significant gain in system capacity.

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