Rate and Power Throttling for Traffic Asymmetry in Reverse TDD HetNets

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Abstract

In this paper, sum link capacity expressions for successive interference cancellation (SIC) and regarding interference as noise (IAN) in reverse time-division duplexing (RTDD) heterogeneous cellular network are derived. The considered RTDD network always operates 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. Rate and power throttling are used in the uplink (UL) for both IAN and SIC to consider an asymmetric traffic network (DL≫UL). System-level simulations are performed to compare the overall system throughput of IAN and SIC for different DL/UL ratios. It is observed that rate or power-throttled SIC performs better than rate-throttled IAN and worse than power-throttled IAN.

1 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 base station (SBS) to support local hotspot requirements. Since the macro tier and the small tier use the same set of resource blocks (RBs), cross-tier interference problems may arise in the co-channel deployment of a HetNet. 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, as shown in Fig. 1, which exploits the wired backhaul to reduce the interference between MBS and SBS. An RTDD frame consists of two frames with the reversed order of the downlink (DL) and uplink (UL) transmission across macro and small tiers, as shown in Fig. 2. In contrast to exploiting the wired backhaul, an interference alignment scheme is proposed in [3] to reduce interference between the base stations (BSs) of an RTDD HetNet having multiple antennas. In both [2, 3], the interference between the user equipments (UEs) is treated as noise, which would lead to reduced DL rates. This is of particular concern in an RTDD HetNet with asymmetric traffic requirements (DL≫UL) [4] since one cannot increase the number of DL subframes in both of the tiers due to the inherent frame structure as shown in Fig. 2.

In order to increase the DL rates, the interference at the UE is removed by using successive interference cancellation (SIC) that is achieved by decoding, regenerating, and subtracting the interference signal from the received signal. Throttling (setting an upper bound) the UL capacity in both IAN and SIC is proposed to consider an asymmetric traffic network. Through system-level simulations, the throughput of IAN and SIC for both rate and power throttling is compared and shown that SIC performs better in rate throttling, whereas IAN performs better in power throttling.

2 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

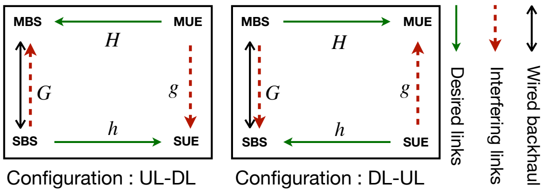

Fig. 1: Two possible configurations of an RTDD Hetnet

5:5	0	1	2	3	4	5	6	7	8	9
MBS	DL	DL	DL	DL	DL	UL	UL	UL	UL	UL
SBS	UL	UL	UL	UL	UL	DL	DL	DL	DL	DL

Fig. 2: An RTDD frame where the MBS and SBS set their DL and UL frames in reverse order.

the operations of the MBS-SBS pair. Let X_{MBS} and P_{MBS} denote the transmission symbol and power of the MBS in one RB, such that $X_{\text{MBS}} \sim \mathcal{CN}(0, \sqrt{P_{\text{MBS}}})$ while Z_{MBS} denotes the additive white Gaussian noise (AWGN) at the MBS. Similar notations are also used for SBS, macro UE (MUE), and small UE (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.

Assume the transmissions across both tiers to be perfectly synchronized, and let the received symbols at MBS and SUE for UL-DL configuration be denoted by Y_{MBS} and Y_{SUE}, respectively. These can be modelled as

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

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

The corresponding signal-to-interference-plus-noise ratios (SINRs) at MBS and SUE are given by

$$\text{SINR}_{\text{MBS}}^{\text{IAN}} = P_{\text{MUE}}|H|^2/(P_{\text{SBS}}|G|^2 + \sigma^2), \tag{3}$$

$$\text{SINR}_{\text{SUE}}^{\text{IAN}} = P_{\text{SBS}}|h|^2/(P_{\text{MUE}}|g|^2 + \sigma^2), \tag{4}$$

where the noise variance σ^2 at all the nodes is assumed to be equal. By symmetry from Fig. 1, the corresponding equations for the DL-UL configuration can be obtained by swapping H and h, MBS and SBS, MUE and SUE in the above equations. Hence, we only derive the equations for UL-DL configuration in this paper. Assuming that the interference channel estimates are known or perfectly estimated, the procedure that is given in [2] will remove the interference between the BSs. To get an accurate estimate of both the desired and interference links, the pilots that are transmitted by MUE and SBS are assumed to be orthogonal. After exploiting the wired backhaul between BSs, as given in [2], (3) becomes

$$\text{SNR}_{\text{MBS}}^{\text{IAN}} = P_{\text{MUE}}|H|^2/\sigma^2. \tag{5}$$

In asymmetric traffic applications, UEs typically need more data in DL than in UL [4]. For example, the maximum UL information rate depends on the type of application such as web browsing, audio and video calling. To achieve the SNR given by (5), the system should always operate in an RTDD framework as shown in Fig. 2 which means it cannot accommodate for any asymmetry in DL/UL data demands. Therefore, an upper bound (R_o) on the UL data rate is set to take this scenario into account. Let $C_{\text{MUE}}^{\text{IAN}}$ denote the maximum rate at which the MUE can transmit such that MBS can decode, which can be written in terms of $\text{SNR}_{\text{MBS}}^{\text{IAN}}$ and the upper bound (R_o) as

$$C_{\text{MUE}}^{\text{IAN}} = \min\left\{B_o \log_2\left(1 + \text{SNR}_{\text{MBS}}^{\text{IAN}}\right), R_o\right\}, \tag{6}$$

where B_o is the bandwidth of one RB. Substituting SNR from (5), we can represent (6) as

$$C_{\text{MUE}}^{\text{IAN}} = \overbrace{B_o \log_2\left(1 + P_{\text{MUE}}\overline{|H|^2}/\sigma^2\right)}^{\text{rate throttling}} \quad \text{and} \quad C_{\text{MUE}}^{\text{IAN}} = \overbrace{B_o \log_2\left(1 + \overline{P_{\text{MUE}}}|H|^2/\sigma^2\right)}^{\text{power throttling}}, \tag{7}$$

where $\overline{|H|^2} = \min(|H|^2, (2^{R_o/B_o} - 1)\sigma^2/P_{\text{MUE}})$ and $\overline{P_{\text{MUE}}} = \min\left\{P_{\text{MUE}}, (2^{R_o/B_o} - 1)\sigma^2/|H|^2\right\}$. From (4), the DL capacity for rate and power throttling is given by

$$C_{\text{SBS}}^{\text{IAN}} = B_o \log_2\left(1 + P_{\text{SBS}}|h|^2/(P_{\text{MUE}}|g|^2 + \sigma^2)\right) \text{ and } C_{\text{SBS}}^{\text{IAN}} = B_o \log_2\left(1 + P_{\text{SBS}}|h|^2/(\overline{P_{\text{MUE}}}|g|^2 + \sigma^2)\right). \tag{8}$$

As denoted in (7), the UL threshold can be implemented either by throttling the rate or the power in the UL. Rate throttling can be achieved by considering an effective channel strength of $\overline{|H|^2}$ instead of $|H|^2$ while power throttling can be accomplished by using UL power of $\overline{P_{\text{MUE}}}$ instead of P_{MUE}. Though power throttling in UL can decrease the interference experienced by the SUE, it has to always operate at the UL capacity which means the bit error rate might increase if proper codes are not designed. This is not the case for rate throttling since one does not always operate at the capacity and hence can provide better error rates by adding more and more redundant bits for error control coding if the channel gets stronger. The sum link capacity achieved by the desired links of UL-DL configuration is given by summing (7) and (8) as

$$C_{\text{sum}}^{\text{IAN}} = C_{\text{SBS}}^{\text{IAN}} + C_{\text{MUE}}^{\text{IAN}}. \tag{9}$$

3 SIC in Reverse-TDD HetNets

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 assuming they know the interference constellation space. In the UL-DL configuration of Fig. 1, in order to completely eliminate the cross-tier interference, the SUE should decode all the data transmitted by the MUE. If we let C_{MUE}^{*} be the maximum rate at which the MUE can transmit so that the SUE can decode its data, then

$$C_{\text{MUE}}^{*} = B_o \log_2(1 + \text{SINR of MUE signal at SUE}) = B_o \log_2(1 + P_{\text{MUE}}|g|^2/(P_{\text{SBS}}|h|^2 + \sigma^2)). \tag{10}$$

However, the capacity equation corresponding to (5) gives the maximum rate at which the MUE can transmit so that its data can be decoded by MBS. Let $C_{\text{MUE}}^{\text{SIC}}$ be the maximum data rate at which the MUE can transmit so that its data can be decoded both at the SUE and MBS. The expression for $C_{\text{MUE}}^{\text{SIC}}$ after introducing an uplink threshold would be

$$C_{\text{MUE}}^{\text{SIC}} = \min\left\{C_{\text{MUE}}^{*}, B_o \log_2\left(1 + \text{SNR}_{\text{MBS}}^{\text{IAN}}\right), R_o\right\}. \tag{11}$$

Now, consider 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 $P_{\text{MUE}}|g|^2$ in (4) converges to zero and the SINR becomes $\text{SNR}_{\text{SUE}}^{\text{SIC}} = P_{\text{SBS}}|h|^2/\sigma^2$. Let $C_{\text{SBS}}^{\text{SIC}}$ and $C_{\text{sum}}^{\text{SIC}}$ denote the DL and sum link capacity in SIC respectively, so that

$$C_{\text{SBS}}^{\text{SIC}} = B_o \log_2\left(1 + \text{SNR}_{\text{SUE}}^{\text{SIC}}\right), \tag{12}$$

$$C_{\text{sum}}^{\text{SIC}} = C_{\text{SBS}}^{\text{SIC}} + C_{\text{MUE}}^{\text{SIC}}. \tag{13}$$

Unlike in IAN, the DL capacity term $C_{\text{SBS}}^{\text{SIC}}$ for SIC does not change for power or rate throttling and hence it does not matter as to which throttling method is used. Similar to IAN, power throttling helps in saving some power at the MUE end but it assumes the availability of codes that can always operate at the capacity, failing which may lead to high bit error rates.

4 Simulations and 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 [5]. Thus,

Table 1: 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	
Total no. of MUEs / SUEs / RBs	32	
No. of SBSs × No. of SUEs per SBS	4×8	
Radius of macrocell (R)	150 m	

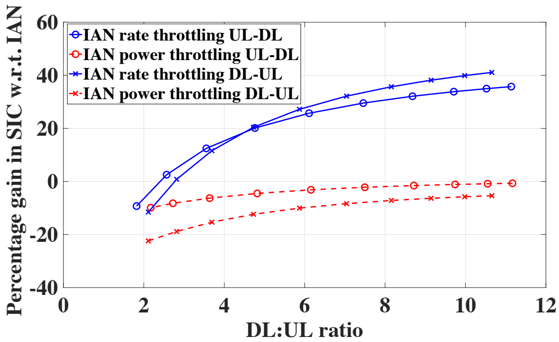

Fig. 3: Percentage gain in the system throughput for SIC w.r.t. to IAN for different DL/UL ratios.

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, and for each deployment, 1000 realizations of the small-scale fading have been simulated. All the other relevant simulation parameters are listed in Table 1. Each RB is randomly allocated to some MUE and SUE, and for 32 MUEs and 32 SUEs, 32 RBs are utilized.

A comparison of IAN and SIC is made by calculating the gain in the system throughput of SIC w.r.t. IAN for the sake of brevity. As R_o for UL-DL configuration is varied, the corresponding DL/UL ratios in the macro tier and the percentage gain in the system throughput of SIC w.r.t. IAN is noted. These are plotted, as shown in Fig. 3 for both rate and power throttling of IAN compared with the rate or power-throttled SIC. The same is repeated for the DL-UL configuration, while the DL/UL ratio computed would be of the small tier. Note that only interference-free rates ($|g|^2 = 0$) are considered in computing the DL/UL ratio. From the graph, we can infer that in asymmetric traffic networks, throttled SIC gives better performance than rate-throttled IAN and worse performance than power-throttled IAN. Hence, at high DL/UL ratios, IAN should be used when power throttling is done, and SIC should be used when rate throttling is done. For smaller DL/UL ratios, one can see that IAN performs better than SIC in both rate and power throttlings since the gains in Fig. 3 are negative for all the cases.

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