Decentralized spectrum allocation and beamforming for downlink in a two-tier macro femtocell network

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Abstract

This research examines a variety of spectrum allocation and partitioning algorithms with the goal of reducing cross-tier interference in downlink beamforming scenarios. By increasing SIR, beamforming improves spectrum efficiency by enabling more femtocells to share the microcell's spectrum. First, we build a straightforward centralized system as the best option for deciding whether femtocells should use the whole or partitioned spectrum, and then we provide a workable decentralized method. In this study, we look at two alternative probabilistic femtocell base station (HeNB) selection strategies with the aim of making the most of limited data on received signal strength. Under two distinct selection procedures, we manage the outage probability for a microcell user: equal selection and interference weighted selection. By comparing our decentralized approach to a conventional cochannel deployment strategy, we demonstrate significant improvements in both outage probability and cell capacity. We further show that our proposed approach outperforms the fixed-ratio spectrum-partitioning method while providing comparable cell utility to the centralized approach.

Introduction

As a high-bandwidth, low-cost solution for the next generation of wireless networks, femtocell deployment has caught the attention of mobile carriers. Femtocells employ IP networks to backhaul incoming traffic while utilizing a negligible amount of power, significantly enhancing interior coverage. In long-term evolution (LTE) networks, femtocells provide mobile convergence services over the broadband backhaul while operating in the licensed spectrum owned by a mobile operator. Some of its benefits include increased capacity, better coverage, and reduced power consumption on the handset side [1]. However, when microcell and femtocell networks coexist at the same frequency, cross-tier and co-tier interference offers additional control challenges. There has been a lot of work done on the subject of managing interference between co-tiers [2-7], but inter-tier interference is still a significant technical challenge [1,8]. Two-tier networks have been investigated in the context of uplink capacity in overlapping macro-cell/microcell code division multiple access (CDMA) systems [9,10]. This may not always be the case for femtocell networks that have been established without any outside help [8]. In a two-tier network, one of the biggest technical implementation challenges is dealing with cross-tier interference between current microcell and femtocell networks [1,8]. To avoid negatively impacting the functioning of the existing microcell network, femtocells should be designed to minimize low-level interference [11,12]. It has been extensively simulated how well femtocells and microcells would work when deployed in a cochannel.

[13], in particular with regards to interference across different tiers. Having microcell and femtocell networks operate on different frequency bands may help prevent cross-tier interference [14]. The scarcity of radio resources and the complexities of spectrum distribution make spectrum sharing the preferable option.

a model of the system

In this model, there is a microcell network that serves as the backbone for a plethora of femtocell networks. Within a cell radius of Rm, there is a single macrocell user (MUE) and a single microcell ephemeral eNB (MeNB). Where Kt is a collection of Heterogeneous Network Base Stations, the radius of each femtocell network is Rf (Rf Rm). Femtocells are miniature, standalone cell towers that may serve as a private network for a select number of approved customers within a building. Each HeNB i is assumed to be serving a femtocell user (HUE i). Femtocells utilise the same frequencies as their macrocell counterparts and are installed on top of the existing macrocell infrastructure. Because of frequency band limits, femtocells and microcells sometimes share some or all of the same frequencies, which may lead to interference with other networks. Interactions between femtocell and microcell networks result in cross-tier interference, whereas neighbor-boring femtocells cause interference at the co-tier level. Since noise has such a little effect on an interference-limited network, we will treat it as if it were just thermal background noise in a small town. The purpose of this study is to decrease downlink cross-tier interference between microcells and femtocells by splitting highly interfering femtocells. We use beamforming transmission, which increases the strength of the intended signal while decreasing the volume of background noise. The Mknes and HeNBs are assumed to have beamforming antennas, but the MUEs and HUEs are assumed to not.

Third-best spectrum-splitting proportion and single-source algorithm

Heterogeneous femto-microcell networks are vulnerable to severe performance loss due to cross-tier interference generated by neighbouring active users. Spectrum sharing and spectrum partitioning are two methods for reducing interference. While the quantity of cross-tier interference is reduced by using partitioned spectrum, the amount of usable spectrum is decreased. When users pool their spectrum resources, they benefit from more available frequencies but are subject to more disruptive cross-tier interference. Hybrid spectrum utilization, which takes advantage of both kinds of spectrums, is also an option. Significant cross-tier interference may be experienced by UEs when they are placed close to an active cross-tier transmitter, such as a MUE close to active HeNBs or a HUE close to an active Men. The spectrum must be split in half to prevent this from happening. Less than half of it, shared spectrum Both microcell and femtocell networks utilize the same frequency without interfering with one another. The remaining spectrum is "partitioned," meaning it is reserved for use by femtocell networks. This article addresses two issues related to reducing cross-tier interference. The difficulty of deciding which HeNBs should utilize the partitioned spectrum is called the spectrum allocateton problem. To determine how much spectrum should be shared and how much should be partitioned, we must solve the spectrum partitioning issue. We shall examine in depth how the channel input from each HeNB i is necessary for optimum spectrum allocation in Section. We first determine the optimal spectrum partitioning ratio, v p, as a function of the fraction of a cell's spectrum that is partitioned, | Kp|, using an analytical method.

table 1 Number of beams and beamforming gain

N_b	θ_m	$\bar{g}_m$	$\bar{g}_s$	Ψ_m, Ψ_f (dB)
1	2π	0.00	0.00	0.00
4	$\pi/2$	9.84	-30.00	6.02
8	$\pi/4$	18.37	-30.00	9.03

Distributed Systems for Allocating and Partitioning the Spectrum

Here, we provide a system for the distributed allocation and division of the spectrum. Each HeNB in our method may choose to utilize either the whole or partitioned spectrum, with just the barest minimum of cross-tier feedback.

Distributed algorithm

The decentralized spectrum allocation algorithm needs more data than only HUE and HeNB SIR measurement tests. Figure 3 depicts the techniques for transmitting and receiving control signals, while Algorithm 2 describes a decentralized strategy to distributing spectrum. i In the first trial, MeNB sends a pilot signal through beamforming transmission. If HUE i has the required SIR q f, it will inform its linked HeNB i that it is part of F1; otherwise, HUE i will inform its connected HeNB i that it is part of F2. In the second experiment, MUE broadcasts a pilot signal in all directions, and HeNB i measures the strength of the signal it receives from MUE to determine the level of interference it creates. HeNB i reports interference from MUE ii, which in turn reports it to HeNB ii. MUE collects SF1 data and relays it to the F1 HeNBs. In this section, we will examine the impact of two distinct HeNB selection policies on cross-tier feedback from MUE to HeNBs: the equal selection policy and the inter ference weighted selection strategy. In order to conform to parity. To implement the SF1 selection policy, the MUE must send a signal via the backhaul to all F1 HeNBs. However, when MUE employs the interference weighted selection method, the broadcast pilot signal intensity is adjusted such that PS:= PtSF1. Since each HeNB I already knows the channel response hi between MUE and HeNB I thanks to the earlier cross-tier handshake, HeNB I may estimate I in ii and so recover SF1 from the PS signal it has received. With a probability ps, each HeNB I decides whether to use the whole or partitioned spectrum. Instead of manually collecting data on channel status at the MUE, a probabilistic judgment procedure is used by each HeNB. In Section 4.2, we lay out the procedures that must be followed in order to get PS from SF1.

Evaluation of Performances

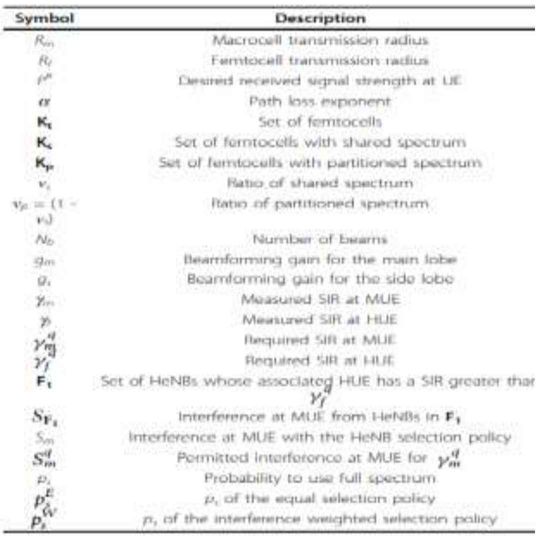
Here, we take into account the typical number of HeNBs making full use of the spectrum and utilize simulations to determine the spectrum's efficiency. The likelihood of outages in the centralized, decentralized, and spectrum-free schemes is examined. We also look at the connection between cell functionality and the ratio of common spectra. For the sake of our simulations, we set |Kt| equal to 100, assuming that each microcell site has

100 femtocells. Our calculations are based on a centrally positioned Men with a 500-meter transmission range (Rm). The Rf transmission range of each HeNB inside the microcell site is 20 meters. We have performed extensive simulations over several randomly generated topologies and shown the average outcomes here. We used wm = 10 for the MUE utility weight and wf = 1 for the HUE utility weight. Beamforming sharpness of the main lobe is represented by the number of beams in a MeNB or HeNB, which may be Nb Î 1, 4, or 8.

$$\left(\text{i.e., } \theta_m = \frac{2\pi}{N_b}\right).$$

The beam gains of the main lobe and the side lobe are denoted by gm and gs, respectively, in dB scale and the average beamforming gain in the twotier network by Ψ(Nb). The path loss exponent parameters a's for MUE and HUEs are uniformly distributed in [3,5]a . We set the UE noise figure at -174 dBm/Hz and the spectrum bandwidth at 20 MHz which follow the 3GPP LTE specifications. The system parameters and notations are summarized in Table 3.

table 3 Definition of notations



Symbol	Description
R_m	Macrocell transmission radius
R_f	Femtocell transmission radius
P^R	Desired received signal strength at UE
α	Path loss exponent
$\mathbf{K}_t$	Set of femtocells
$\mathbf{K}_s$	Set of femtocells with shared spectrum
$\mathbf{K}_p$	Set of femtocells with partitioned spectrum
ν_s	Ratio of shared spectrum
$\nu_p = (1 - \nu_s)$	Ratio of partitioned spectrum
N_b	Number of beams
g_m	Beamforming gain for the main lobe
g_s	Beamforming gain for the side lobe
γ_m	Measured SIR at MUE
γ_f	Measured SIR at HUE
γ_m^q	Required SIR at MUE
γ_f^q	Required SIR at HUE
$\mathbf{F}_t$	Set of HeNBs whose associated HUE has a SIR greater than γ_f^q
$S_{\mathbf{F}_t}$	Interference at MUE from HeNBs in $\mathbf{F}_t$
S_m	Interference at MUE with the HeNB selection policy
S_m^q	Permitted interference at MUE for γ_m^q
p_s	Probability to use full spectrum
p_s^E	p_s of the equal selection policy
p_s^W	p_s of the interference weighted selection policy

The distance-based allocation method, which divides femtocells into inner and outer kinds depending on their distance from MeNB, is first compared to the centralized and decentralized spectrum allocation schemes. Spectrum is divided into inner and outside femtocells, with the latter using the former. Due to the lack of consideration for beamforming settings in prior hybrid spectrum methods, we use the distance-based strategy with beamforming in [23]. Figure 5 depicts the CDF (cumulative distribution function) of |Ks| when q m = 0 dB, and Figure 6 depicts the average number E[|Ks|] of HeNBs that utilise the whole spectrum. If the beamforming is more precise, then more HeNBs will be able to share the spectrum with the microcell network, increasing the value of |Ks|. For a particular beamform ing gain, the 'Centra lized' centralized algorithm has the maximum |Ks|. Both the equal selection policy (labeled 'Decentralized Equal') and the interference weighted selection policy (labeled 'Decentralized Weight') are examples of decentralized systems whose |Ks| are very close to that of the centralized scheme. The 'Dis tance-based' approach uses a set distance threshold and the average channel model without knowledge of the current channel state, hence it has a smaller number of E[|Ks|]. Using interference cancellation using MIMO and beamforming communication methods, we can reduce interference. However, the outage performance is still severely impacted by cross-tier interference if all HeNBs share the macrocell spectrum without interference mitigation, and this is true even with beamforming transmission. Figure 7 depicts MUE's outage performance with and without cross-tier interference mitigation. Here we show the 'Without IM' version of the cochannel deployment with beam forming transmission, where all HeNBs use the same microcell spectrum. The chance of an outage in MUE increases to between [10-1] and [10-2] if a spectrum partitioning technique is not used. By distributing most likely severely interference-generating HeNBs to the partitioned spectrum, our decentralized allocation and partitioning techniques effectively lower the outage probability. It also demonstrates that an increase in beamforming gain reduces the likelihood of an outage. Note that the distance-based scheme does not suffer an outage either due to its conservative spectrum sharing approach, i.e., lesser number of |Ks|, and the centralized scheme does not experience an outage at all due to the utilization of all the co-tier and cross-tier channel information.

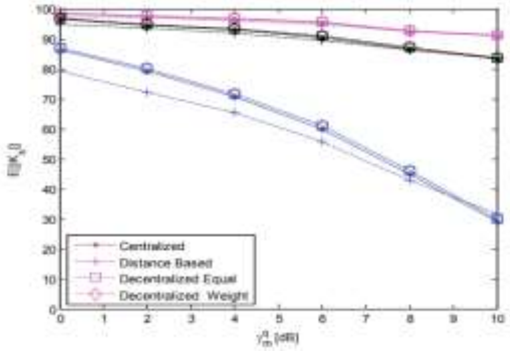


figure 1 Average number of sharing HeNBs versus required SIR at MUE.

Figure 1 highlights the relationship between the SIR requirement and the outage probability and the ensuing E[|Ks|]. In the 'Without IM' scheme, all HeNBs utilize the cochannel with the microcell network, which results in the very disruptive cross-tier interference. When Nb = 4, the chance of a 'Without IM' outage is close to 10-1, but at Nb = 8, it drops to 10-2. It demonstrates that the outage probability is much reduced thanks to interference mitigation, particularly when the decentralized weight strategy is used. In most cases, the frequency of the outage increases as the SIR requirement becomes more stringent. Figure 1 shows that when q m increases, the out-of-age probability reduces in the proposed method, denoted by E[|Ks|]. Because of this, we see that as E[|Ks|] becomes larger—that is, as q m decreases—the likelihood of an outage rises. Figure 9 displays the cell capacity at MUE q m with Nb = 1, and Figure 10 displays the utility performance according to the requirement SIR. Our decentralized spectrum splitting strategy is compared to a centralized approach with fixed ratios of vs = 0.5 and 0.9. when illustrated in Figure 1, when q m rises, the capacity of each UE grows logarithmically, yet |Ks| shrinks. As a result, there is a little rise in cell capacity as q m increases. When compared to the centralized strategy, our probabilistic spectrum allocation and partitioning techniques perform similarly in terms of cell capacity and utility. However, the cell capacity and utility of the fixed spectrum parti toning scheme with s = 0.5 and 0.9 are lower than those of our systems. Cell capacity and utility are both lowest in the 'Without IM' scheme because to the extreme cross-tier interference that occurs.

conclusion

To reduce cross-tier interference in downlink beamforming situations, we offer spectrum allocation and partitioning techniques. With efficiency and equity in mind, we analytically computed the ideal ratio of spectrum partitioning to optimize cell utility. Our distributed method needs less cross-tier feedback because of the probabilistic aggregation of cross-tier interference. In terms of overall cell capacity and utility, our simulation findings demonstrate that the proposed decentralized method with the interference weighted HeNB selection criteria is on par with the centralized system. The cross-tier interference issue in a large-scale two-tier network is also efficiently resolved by the employment of reduced cross-tier control overhead.

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