Distributed spectrum allocation and partitioning in a two-tier macro femtocell network with downlink beamforming

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Abstract

With downlink beamforming cross-tier interference as a target, this study investigates various spectrum allocation and partitioning strategies. The number of femtocells that may share the microcell's spectrum is increased by beamforming, which improves spectrum efficiency by boosting SIR. We construct a simple centralised system and then provide a practical decentralised solution so that you can choose between utilising the complete spectrum or partitioning it by femtocells with acceptable control overhead. This study investigates two distinct probabilistic femtocell base station (HeNB) selection algorithms with the goal of making the most efficient use of limited data on the received signal strength. We use two separate selection policies—interference weighted selection and equal selection—to control the microcell user's outage probability. We show that our decentralised method outperforms a traditional cochannel deployment strategy in terms of cell capacity and outage probability via performance assessment. Moreover, we prove that our suggested approach beats the fixed-ratio spectrum splitting strategy while maintaining cell utility on par with the centralised system.

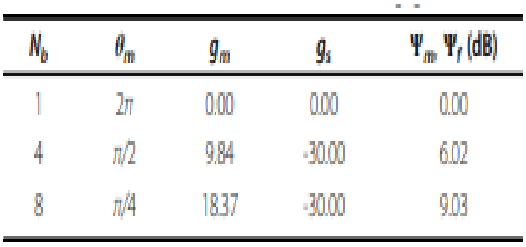
Introduction

Mobile operators are taking notice of femtocell deployment as a high-bandwidth, low-cost option for the next evolution of wireless networks. Femtocells employ IP networks to backhaul incoming traffic in an energy-efficient manner, thereby enhancing indoor coverage. In the licensed spectrum that is managed by a mobile operator, femtocells provide mobile convergence services via the broadband backhaul in long-term evolution (LTE) networks. Among its many benefits are increased capacity, better coverage, and reduced power consumption by handsets [1]. When microcell and femtocell networks coexist at the same frequency, extra control challenges arise from cross-tier interference and co-tier interference between the two types of mobile devices. There is a lot of literature on co-tier interference management [2–7], however solving interference between tiers is still a big technical challenge [1,8]. Prior research on two-tier networks examined uplink capacity in code division multiple access (CDMA) systems that overlayed macro-cells and microcells [9,10]. This can be an unreasonable expectation for femtocell networks that are established separately [8]. In a two-tier network, one of the most important technical challenges is managing interference between the microcell and femtocell layers [1,8]. To minimize their impact on the existing microcell network's performance, femtocells should be designed to minimize low-level interference [11,12]. It has been thoroughly investigated via simulations in the past how well cochannel deployment of femtocells and microcells performs. [13], especially in cases of interaction across several tiers. Keeping microcell and femtocell networks on different frequency bands is one strategy for minimizing interference between the two tiers [14]. However, since radio resources are finite and spectrum distribution is complicated, sharing the same spectrum is recommended. the system's model Our model involves a microcell network and several femtocell networks, arranged in a two-tiered architecture. Within a cell radius of Rm, the microcell network is comprised of a single macrocell user (MUE) and a single microcell ephemeral NB (MeNB). A group of heterogeneous network base stations is represented by Kt in each femtocell network, and each network has a radius of Rf (Rf Rm). To ensure confidentiality and safety, femtocells are designed to provide access only to a select few authorized subscribers housed in a building that is within the femtocell's radio signal range. Every HeNB i is assumed to have a femtocell user (HUE i) connected to it. Perched atop the existing macrocell network, femtocells share the same frequency bands. Microcells and femtocells are also constrained by spectrum constraints and must share the same frequency range, which might lead to interference with neighboring networks. When femtocells communicate with microcells, it's called cross-tier interference; when femtocells bore into their neighbors, it's called co-tier interference. Noise will be treated as basic city thermal background noise since it has no effect on an interference-limited network. To lessen the downlink cross-tier interference between microcells and femtocells, we partition femtocells that are very interfering. Our method, known as beamforming transmission, increases the strength of the desired signal while decreasing background noise. Although the user equipment (MUEs and HUEs) presumably do not have beamforming antennas, we presume that the base stations (Meknes and HeNBs) have.

The single-source method and third-best spectrum-splitting percentage

The cross-tier interference caused by nearby active users may significantly reduce the performance of heterogeneous femto-microcell networks. One way to lessen interference is to share the spectrum or divide it up into smaller portions. Partitioned spectrum reduces the amount of cross-tier interference but decreases the amount of accessible spectrum overall. Users experience more disruptive cross-tier interference when they pool their spectrum resources, but they also benefit from more accessible frequencies. Another alternative is hybrid spectrum use, which combines the two types of spectrums. An active cross-tier transmitter, such a Men or HeNB, may cause UEs to suffer from severe cross-tier interference. This can happen when a MUE is located near an active HeNB, or when a HUE is located near an active Men. This can't happen until the spectrum is divided in half. Just about half of that, 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

Aside from HUE and HeNB SIR measurement tests, the decentralized spectrum allocation algorithm requires. In Algorithm 2, we outline a decentralized approach to allocating spectrum, and in Figure 3, we outline the methods for sending and receiving control signals. i MeNB uses beamforming transmission to send a pilot signal in the first test. HUE i tells its connected HeNB i that it is part of F1 if it has the necessary SIR q f ; otherwise, it tells its connected HeNB i that it is part of F2. In the second experiment, MUE sends out an omnidirectional pilot signal, and HeNB i calculates the intensity of the interference it causes by measuring the strength of the signal it receives from MUE. Cross-tier interference is communicated from HeNB i to MUE ii. iii. MUE measures SF1 and communicates it to the HeNBs in F1. In this part, we will discuss two different HeNB selection strategies, the equal selection policy and the inter ference weighted selection strategy, and how they affect the cross-tier feedback from MUE to HeNBs. To comply with the equal. Selection policy, MUE must broadcast SF1 information to all F1 HeNBs through the backhaul. When using the interference weighted selection approach, however, MUE modifies the strength of the transmitted pilot signal such that PS:= PtSF1. As a result of the previous cross-tier handshake, each HeNB I knows the channel response hi between MUE and HeNB I, allowing HeNB I to estimate I in ii, allowing HeNB I to recover SF1 from the received signal of PS. Each HeNB I chooses whether to employ the complete spectrum or the partitioned spectrum with a probability ps. Instead of the heavy lifting of gathering channel status information at the MUE, each HeNB uses a probabilistic decision process instead. In Section 4.2, we detail the steps necessary to derive PS from SF1.

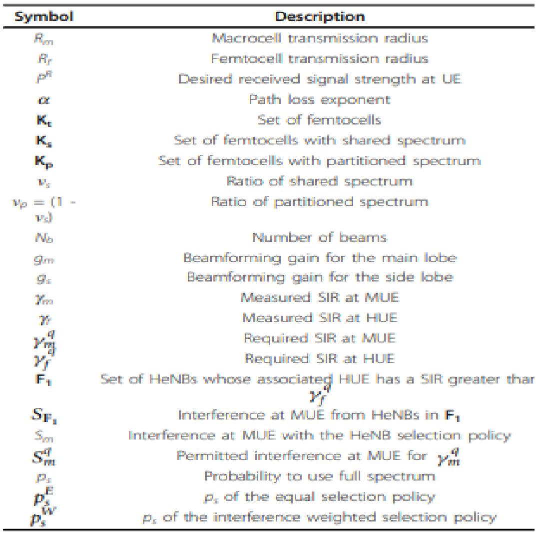
Evaluation of Performances

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
$\mathbf{F_1}$	Set of HeNBs whose associated HUE has a SIR greater than γ_f^q
$S_{\mathbf{F_1}}$	Interference at MUE from HeNBs in $\mathbf{F_1}$
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.

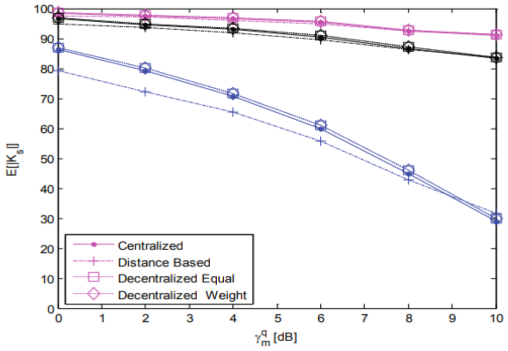


figure 1 Average number of sharing HeNBs versus required SIR at MUE.

The correlation between the SIR need, the outage likelihood, and the consequent E[|Ks|] is shown in Figure 1. The 'Without IM' approach causes very annoying cross-tier interference as all HeNBs use the cochannel with the microcell network. With Nb = 4, the 'Without IM' outage likelihood is around 10-1, but it lowers to 10-2 when Nb = 8. Using the decentralized weight technique in particular, it shows that interference mitigation significantly lowers the outage likelihood. The outage frequency often rises in tandem with the tightening of the SIR requirement. As shown in Figure 1, the out-of-age probability, E[|Ks|], decreases in the suggested technique as q m grows. This means that the probability of an outage increases as E[|Ks|] becomes higher, i.e., as q m falls. Figure 10 shows the utility performance according to the requirement SIR, and Figure 9 shows the cell capacity at MUE q m with Nb = 1. We evaluate our decentralized spectrum splitting method against a centralized one using vs = 0.5 and 0.9 as fixed ratios. The capacity of each UE increases logarithmically when q m rises, as seen in Figure 1, but |Ks| diminishes. Consequently, as q m rises, cell capacity somewhat increases. Our probabilistic spectrum allocation and partitioning methods are as efficient and effective as the centralized approach with respect to cell capacity. With s = 0.5 and 0.9, the fixed spectrum parti toning technique has lower cell capacity and utility than our solutions. The "Without IM" method has the lowest cell capacity and utility due to the severe cross-tier interference that occurs.

final thought

We provide methods for allocating and dividing spectrum to minimize cross-tier interference in downlink beamforming scenarios. In order to maximize cell utility, we analytically calculated the optimal spectrum partitioning ratio while keeping equity and efficiency in mind. Since cross-tier interference is probabilistically aggregated, our distributed technique requires less cross-tier feedback. Our simulation results show that the suggested decentralized approach using the interference weighted HeNB selection criterion is competitive with the centralized system in terms of total cell capacity and utility. The use of decreased cross-tier control overhead also effectively resolves the cross-tier interference problem in large-scale two-tier networks.

Works Cited

Femtocell networks: a survey, by V. Chandrasekhar, J. Andrews, and A. Gatherer [1]. Press Release from IEEE Communications Magazine, Volume 46, Issue 9, Pages 59–67 (2008)

[2]. J. Lee, B. Kim, and J. Kwon “Utility-Based Subchannel Allocation for OFDMA Femtocell Networks” (IEEE, 2011), in Computer Communications and Networks (ICCCN), 20th International Conference on, pp. 1-6 (2011).

[3]. J. Zhang, G. De La Roche, A. Valcarce, and D. López-Pérez, OFDMA femtocells: a road map for interference avoidance. Publication: Communications Magazine, IEEE. Volume 47, Issue 9, Pages 41–48 (2009)

[4]. H. Choo, C. Oh, M. Chung, and T. Lee In OFDMA-based cellular networks, a new approach to frequency planning for femtocells is employing fractional frequency reuse. Proceedings of the International Conference on Computer Science and Its Applications, 2010, 6018, 96-106 (2010). doi:10.1007/978-3-642-12179-1_10.

[5]. Paper presented at the 10th annual ACM International Symposium on Mobile Ad hoc Networking and Computing by K. Sundaresan and S. Rangarajan, titled "Efficient resource management in OFDMA femtocells," is published in volume 1. Chapters 33–42, published by ACM in 2009, New Orleans, Louisiana, USA

[6]. Park W and Bahk S Guidelines for the efficient administration of cellular network fixed relay resources. A game-theoretical femtocell channel exchange mechanism, DANCE, was published in Computer Communications in 2009 (vol. 32, no. 4, pp. 703–711). The article may be accessed online at doi:10.1016/j. comcom.2008.11.039. The 14th Annual ACM SIGMOBILE Review on Mobile Computing and Communications, pp. 13–15 (2010)

[8]. J. Andrews, V. Chandrasekhar, Femtocell networks have two tiers: uplink capacity and interference avoidance. Report on Wireless Communications, IEEE Transactions on, vol. 8, no. 7, pp. 3498–3509, 2009

[9]. This work is by S. Kishore, L. Greenstein, H. Poor, and S. Schwartz. Multicell CDMA uplink user capacity using microcell hotspots. Article published in 2006 by IEEE Transactions on Wireless Communications, volume 5, issue 6, pages 1333–1342.

The number ten. D. Sung, C. Kang, and H. Cho Analyzing the capacity of macro/microcellular CDMA systems that handle many kinds of traffic with spectrally overlay! Journal of Transportation Research, Volume 52, Issue 2, Pages 333–346 (2003). that have the DOI 10.1109/ TVT.2002.807128.

3G Home NodeB Study Item Technical Report, 3rd Generation Partnership Project (3GPP) [11]. RFC 25.820, Version 8.1.0, 3GPP (2008-05)

[12]. An examination of the efficiency of two-tier femtocell networks subject to power outages, by Y. Kim, S. Lee, and D. Hong. In: IEEE Transactions on Wireless Communications, volume 9, issue 9, pages 2695–2700 (2010)

[13]. H. Claussen, I Performance of hierarchical cell structures with macro-and co-channel femtocells, in 2007's Personal, Indoor and Mobile Radio Communications. 2007 PIMRC. 18th International Symposium on by the IEEE, volume 1. Published by IEEE in 2007, pages 1–5.

cited as [14]. J. Andrews, V. Chandrasekhar, Spectrum allocation in tiered cellular networks. Publication: Communications, IEEE Transactions on, volume 57, issue 10, pages 3059–3068, 2009

[15]. D Hong, S. Park, Y. Kim, S. Lim, and W. Seo Method for reducing interference in two-tier femtocell networks via beam subset selection. Communications in Wireless Networks, 9(11), 3440–3449 (2010)

[16]. To optimize beamforming for multiuser two-tier networks, Y. Jeong, T. Quek, and H. Shin wrote the paper. Publication: Journal of Communication and Networks, Volume 13, Issue 3, Pages 327-338 (2011)

[17]. A Beamforming Strategy for Common Control Channels in Hierarchical Cell Structure Networks Utilizing Adaptive Beam Patterns and Power Control, C. You, Y. Jung, and S. Cho. Chapter 13, pages 319-326, Journal of Communication and Networks (2011)

[18]. "Hybrid spectrum utilization for overlaying LTE macrocell and femtocell" (Y. Bai, J. Zhou, & L. Chen, 2009), vol. 1, Honolulu, Hawaii, USA: IEEE Press, pp. 1642–1647.

[19]. Mr. Erturk, Mrs. Aki, Mr. Güvenc, and Mrs. Arslan Spectrum Splitting in Macrocell-Femtocell Networks: A Fair and Quality-of-Service-Oriented Approach, in GLOBECOM 2010, 2010 IEEE Global Telecommunications Conference, volume 1, Miami, Florida, USA: IEEE, pages 1-6 (2010)
[20]. M. Jeong, I. Guvenc, F. Watanabe, and H. Inamura Femtocell frequency assignment and coverage area analysis in a hybrid setup for co-channel operation. Published in 2008 by IEEE Communications Letters, volume 12, pages 880-882.