

Hybrid spectrum access model for cognitive femtocell networks

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Abstract: In order to mitigate the interference for macrocell users caused by deploying femtocells (home base-station) in a long term evolution (LTE) system, a hybrid spectrum access model is proposed by means of applying the cognitive radio technology to the femtocell. The femtocell periodically senses the radio environment and opportunistically accesses the usable frequency band so that the frequency spectrum resource is used intelligently. The sensing process is performed in two stages, which are principal sensing in the downlink and assisted sensing in the uplink, respectively. Based on the information obtained from the sensing results, the frequency spectrum can be used flexibly in underlay or overlay modes in the femtocell. Simulation results show that by using the proposed model, the throughput of a femtocell is greatly improved with tolerable interference to macrocell users.

Key words: cognitive radio; frequency spectrum sensing; frequency spectrum accessing; femtocell; macrocell

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There has been increasing interest in deploying femtocells in a long term evolution (LTE) system. A femtocell (home base-station) has a coverage of 10 to 50 m and it is usually placed indoors. Due to a dense spatial reuse of the available radio spectrum, using femtocells can greatly improve the capacity and coverage of the networks^[1]. However, as femtocells reuse the radio resources of macrocells, they may cause cochannel interference (CCI) to macrocell users. Interference decreases the network capacity and results in performance degradation. Handling the interference is one principal challenge for femtocell usage^[2].

Cognitive radio (CR) techniques are proposed to alleviate the interference problem, which allow femtocells to sense the radio resource utilization of macrocells and autonomously adapt to the wireless environment and utilize the spectrum so as to avoid interference to macrocells^[3].

After spectrum sensing, femtocells can employ different approaches to utilize the spectrum. One is for the femtocells to opportunistically access the spectrum only when it is not occupied by the macrocell. This approach is called spectrum overlay^[4-7]. The other is that the femtocells can always access the spectrum if the interference caused to the macrocell users is under a pre-determined threshold. This approach is called spectrum underlay^[8-11].

Both approaches have their merits and drawbacks. For spectrum overlay, the interference caused by femtocells to macrocells can be maintained at a low level if the sensing performance can be guaranteed. But the available amount of spectrum for femtocells depends on the spectrum usages of the macrocell. For spectrum underlay, a femtocell may have more available amount of spectrum, but it may cause higher interference to macrocells. Besides, it requires instantaneous knowledge of interference channels.

A novel dynamic access model is introduced to the femtocell in a two-tier environment taking advantage of the above two CR strategies. In this model, the femtocell flexibly operates in hybrid underlay/overlay spectrum access mode. Spectrum sensing is the first step to detect the interference conditions in a specified band. Then, femtocell users dynamically adjust their access mode based on the sensing results.

This model is motivated by the hybrid automatic repeat request (HARQ) transmission scheme of the LTE network discussed in Ref. [12]. Spectrum sensing is performed accordingly in two stages: the principal sensing to detect the macrocell base-station (evolved node-B (eNB)) downlink transmission, and the assisted sensing to detect the corresponding user equipment (UE) uplink acknowledgement.

The favorable usage mode is selected according to the sensing results in the two stages. The sensing results reflect the link quality with actual pathloss and relevant spatial conditions between the femtocell and macrocell users. By introducing the hybrid spectrum access model to handle the cross-tier interference, the interference recognition can be well managed and higher capacity can be provided via exploiting the spectrum opportunities efficiently. Simulations show that the throughput of the femtocell is greatly improved with tolerable interference to macrocell users.

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1 Network Model

1.1 System configuration

Fig. 1 shows a two-tier LTE network of time division duplex (TDD) type. In the circular macrocell, the UE is served by a high-power eNB, which is usually located at the center with an omnidirectional antenna. The macrocell is overlaid with random distributed femtocells, which has very small signal coverage. For each femtocell, there is a femtocell base station (home evolved node-B (HeNB)) located at the center and multiple home user equipment (HUE) which is connected to the HeNB. The HeNB is in charge of infrastructure functionalities such as service provisioning and profile management for the HUE.

In the macrocell, the transmission is frame-based. As shown in Fig. 1, each frame is partitioned into 10 successive TDMA channels. Such a channel is the unit for radio resources scheduling^[12]. The channel is used for either uplink (UL) transmission or downlink (DL) transmission.

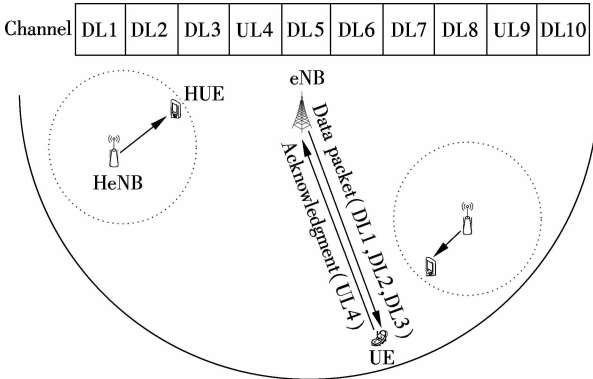


Fig. 1 Infrastructure-based macrocell and multiple overlaying femtocells in a two-tier TDD-LTE network

An important feature of a cellular wireless network is its asymmetry. The available bandwidth for DL transmission is much more than that for UL transmission. So, in this paper we consider the DL transmission of the macrocell.

In the macrocell, HARQ is utilized for transmission, that is, the transmission of a data packet is followed by an acknowledgement from the receiver. As shown in Fig. 1, the DL data transmission of the macrocell is a two-step process between an eNB and its corresponding UE. First, the eNB transmits data packets to the UE on the DL channel. Then, the UE replies an acknowledgement on the UL channel.

Both the macrocells and the femtocells are based on the same communication technology and share identical spectra. The macrocell may suffer from interference if the channel they occupied is being used by a nearby femtocell. As a result, the HeNB shall avoid scheduling the channels occupied by the nearby macrocell to prevent in-

terference.

By incorporating the cognitive capacities, the HeNB can sense its operating environment. Thus, the operation of the femtocell can be adaptively modified by using the radio resource of the macrocell. According to the concept of CR, the macrocell is considered as the primary user, and the femtocell is considered as the secondary user.

It is assumed that neighboring cells follow a synchronized slot structure. In other words, the coupling of the UL/DL channels at the macrocell is known by the femtocells, which enables them to listen to the data sent by the macrocell users in their respective UL and DL channels. The sensing is performed during the guard interval at the beginning of each channel.

1.2 Energy detection

We focus on energy detection in this paper, since it can be simply implemented and used without prior knowledge of primary signal structures.

Before the input signal is applied to the energy detector, it is filtered by the bandpass filter with a bandwidth of W . Let $y(t)$ denote the resulting bandpass signal. The energy detector makes a decision between the following two hypotheses,

$$\begin{aligned} H_0: y(t) &= n(t) & 0 < t \leq T \\ H_1: y(t) &= hs(t) + n(t) & 0 < t \leq T \end{aligned} \quad (1)$$

where T denotes the observation time; $s(t)$ is the transmitted signal from the primary transmitter; $n(t)$ is the zero-mean additive white Gaussian noise (AWGN) with variance σ^2 ; and h is the amplitude gain of the channel. The energy detector squares $y(t)$ and integrates it over the interval of T . Then, the decision statistic Y is compared with the threshold λ . If $Y > \lambda$, the primary signal is determined to be present; otherwise, to be absent.

$$Y = \int_0^T y^2(t) dt \quad (2)$$

Following the work of Ref. [8], Y is shown to have the following distribution,

$$Y \sim \begin{cases} \chi_{2TW}^2 & H_0 \\ \chi_{2TW}^2(2\gamma) & H_1 \end{cases} \quad (3)$$

where χ_{2TW}^2 and $\chi_{2TW}^2(2\gamma)$ denote the central and non-central chi-square distributions, respectively, each with $2TW$ degrees of freedom and a non-centrality parameter of 2γ for the latter distribution. $\gamma = |hs(t)|^2 / \sigma^2$ is the SNR. For simplicity, we assume that the time-bandwidth product TW is an integer number and we denote it by m .

The probabilities of detection and false alarm can be represented as^[13]

$$\begin{aligned} P_d &= p\{Y > \lambda \mid H_1\} = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \\ P_f &= p\{Y > \lambda \mid H_0\} = \frac{\Gamma(m, \lambda/2)}{\Gamma(m)} \end{aligned} \quad (4)$$

where $\Gamma(\cdot)$ and $\Gamma(\cdot, \cdot)$ are the complete and incomplete gamma functions, respectively; $Q_m(\cdot, \cdot)$ is the generalized Marcum Q -function defined as

$$Q_m(a, b) = \int_b^\infty \frac{x^m}{a^{m-1}} \exp\left(-\frac{x^2 + a^2}{2}\right) I_{m-1}(ax) dx \quad (5)$$

where $I_{m-1}(\cdot)$ is the modified Bessel function of the $(m-1)$ -th order.

For simplicity, we ignore channel fading and the path loss is calculated based on the basic path loss model. The propagation loss can be expressed as $L(d) = d^{-\alpha}$, where d represents the distance and α denotes the path loss factor which is a fixed known constant.

2 Hybrid Spectrum Access Model

2.1 Overview

In order to efficiently utilize the spectrum, we present a hybrid spectrum access model based on spectrum sensing. Using this model, a femtocell can choose its transmission mode when accessing the spectrum.

In this model, the HeNB monitors its operating radio environment and searches for the available channels by periodical sensing. Taking advantage of the HARQ transmission scheme of macrocell users, an HeNB performs principal and assisted sensing in the DL channel and the corresponding UL channel, respectively, and detects whether there are any macrocell users in the vicinity.

Normally, channels are available for the femtocell when no primary transmission is detected, which corresponds to the case of both principal and assisted sensing indicating the absence of primary transmission. On the other hand, channels are unavailable for the femtocell when primary transmission is detected, which corresponds to the case of both principal and assisted sensing indicating the presence of primary transmission. In both cases, the sensing results are the same.

However, when the sensing results of the two cases are different, the femtocell is switching to the underlay mode. The first case is that the principal sensing in the DL channel detects the signal of the eNB while the assisted detection in the UL channel does not detect any UE.

The probability of this case, under the condition that primary transmission is on, is

$$P_1 = p\{Y_1 < \lambda_1, Y_2 > \lambda_2 \mid H_1\} = (1 - Q_m(\sqrt{2\gamma_1}, \sqrt{\lambda_1})) Q_m(\sqrt{2\gamma_2}, \sqrt{\lambda_2}) \quad (6)$$

where Y_1 and Y_2 are the decision statistics of the two phases; and λ_1 and λ_2 are the predefined sensing thresholds of the two phases, respectively; γ_1 and γ_2 are the SNR of the eNB signal in the DL channel and the SNR of the UE signal in the UL channel, respectively.

Then, the SNR of the eNB signal and the UE signal can be, respectively, represented as

$$\gamma_1 = \frac{Q_{eNB}}{\sigma^2} d_1^{-\alpha} \quad (7)$$

$$\gamma_2 = \frac{Q_{UE}}{\sigma^2} d_2^{-\alpha} \quad (8)$$

where Q_{eNB} and Q_{UE} are the transmitting power of the eNB and the UE, respectively; and d_1 and d_2 are distances from the femtocell users to the eNB and the corresponding UE, respectively. Because the coverage of the femtocell is small, we consider that the distances of femtocell users to the eNB and the UE are the same.

Substituting Eqs. (7) and (8) into Eq. (6), we can obtain a relationship between P_1 and d_1, d_2 for the given Q_{eNB} and Q_{UE} as

$$P_1 = f(d_1, d_2) \quad (9)$$

As shown in Fig. 2, this is mainly due to the fact that a femtocell is located close to the eNB and far from the operating UE. In this case, the femtocell is unable to detect the UE signal. Meanwhile, the further the femtocell is located from an operating UE, the weaker the DL interference the UE suffers. In this situation, the femtocell can access the DL channel in an underlay way; that is, the femtocell can utilize the DL channel as long as the interference to the UE is under its tolerable interference threshold.

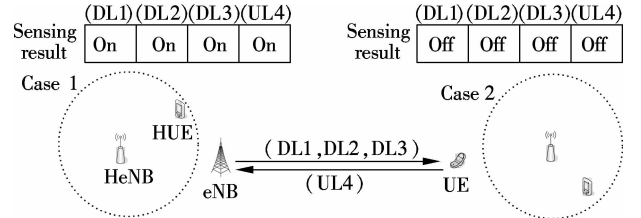


Fig. 2 Spectrum sensing in DL and UL channels

The second case is that the principal sensing in the DL channel does not detect the signal of the eNB while the assisted detection in the UL channel detects a nearby UE. As shown in Fig. 2, this is mainly due to the fact that the femtocell is located far from the eNB and located close to the operating UE. In this case, the femtocell can access the UL channel in an underlay way, which means that the interference to the eNB is under its tolerable interference threshold.

Based on the information obtained from spectrum sensing, the femtocell can flexibly operate in an underlay or overlay mode. It is normally working in an overlay mode if the sensing results in both stages are the same, and it switches to the underlay mode when the sensing results in both steps are varied. Both cases will be discussed in the following.

2.2 Overlay mode

When primary users are transmitting, the probability that the sensing results in both phases indicates that the

presence of primary transmission can be expressed as

$$P_{de} = p\{Y_1 > \lambda_1, Y_2 > \lambda_2 \mid H_1\} = Q_m(\sqrt{2\gamma_1}, \sqrt{\lambda_1}) Q_m(\sqrt{2\gamma_2}, \sqrt{\lambda_2}) \quad (10)$$

When primary users are not transmitting, the probability that the sensing results in both phases indicate the presence of primary transmission can be expressed as

$$P_{fa} = p\{Y_1 > \lambda_1, Y_2 > \lambda_2 \mid H_0\} = \frac{\Gamma(m, \lambda_1/2)}{\Gamma(m)} \frac{\Gamma(m, \lambda_2/2)}{\Gamma(m)} \quad (11)$$

When a femtocell fails to detect the primary signal, it will transmit in the channel simultaneously. In this case, the average throughput of the femtocell can be expressed as

$$T_{\text{overlay-1}} = \frac{1}{2} \int_{r_{\min}}^{r_{\max}} W \left(\log_2 \left(1 + \frac{Q_{\text{SU}} r^{-\alpha}}{\sigma^2 + Q_{\text{eNB}} d_1^{-\alpha}} \right) + \log_2 \left(1 + \frac{Q_{\text{SU}} r^{-\alpha}}{\sigma^2 + Q_{\text{UE}} d_2^{-\alpha}} \right) \right) f(r) dr \quad (12)$$

When primary transmission is off and there is no false alarm in detection, the average throughput of the femtocell can be expressed as

$$T_{\text{overlay-2}} = \int_{r_{\min}}^{r_{\max}} W \left(\log_2 \left(1 + \frac{Q_{\text{SU}} r^{-\alpha}}{\sigma^2} \right) \right) f(r) dr \quad (13)$$

where W is the spectrum bandwidth; Q_{SU} is the transmitting power of the femtocell user; and r is the distance from the femtocell users to the eNB and the corresponding HUE, which is between r_{\max} and r_{\min} . Because the distribution of HUE within the femtocell is random uniform, being subject to the maximum and minimum separation constraints.

$$f(r) = \begin{cases} \frac{1}{r_{\max}^2} - r_{\min}^2 & r_{\min} < r < r_{\max} \\ 0 & \text{otherwise} \end{cases} \quad (14)$$

The average throughput of the femtocell in the overlay mode is

$$T_{\text{overlay}} = P_p (1 - P_{de}) T_{\text{overlay-1}} + (1 - P_p) (1 - P_{fa}) T_{\text{overlay-2}} \quad (15)$$

where P_p is the probability that primary transmission is present.

The coupling between UL and DL channels is of great importance for the implementation of two phase sensing. Compared with traditional single phase sensing, the proposed model improves the reliability of sensing due to the introduction of the combination of two phases. Meanwhile, compared with collaborative sensing among multiple users, it does not need signaling overhead.

2.3 Underlay mode

To maintain enough available spectra for usage of a femtocell, it is necessary for the femtocell to access a

spectrum at times despite the presence of primary transmission. The selection of the underlay strategy and interference management must be carefully investigated.

Femtocells switch to the underlay mode when the sensing results in both phases are varied.

2.3.1 The first case

The first case is that the principal detection in the DL channel indicates absence of the primary signal while the assisted detection in the UL channel indicates presence of the primary signal.

As shown in Fig. 3, in this situation, the femtocell can access the UL channel in an underlay way. But note that the femtocell must carefully evaluate the potential interference in order not to cause unacceptable interference to the eNB. That is, the interference R_s from the femtocell to the eNB must be beyond a threshold r_b , and r_b is determined by the eNB's reception sensitivity and QoS.

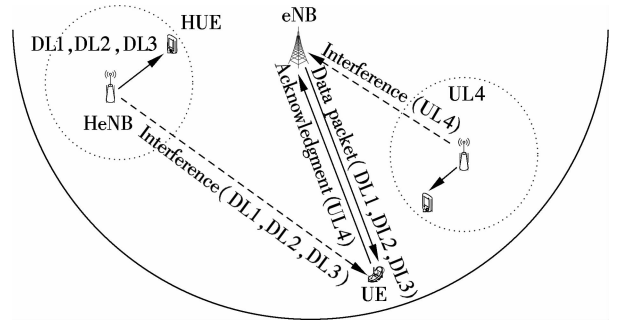


Fig. 3 Channel usage and interference scenario for the two-tier network

The sensing threshold λ_b is used for the HeNB to measure the link between itself and the eNB and make a decision for access or not. If decision statistic $Y_1 < \lambda_b$, the femtocell can access the UL channel. On the contrary, if the decision statistic $Y_1 > \lambda_b$, the femtocell cannot access the UL channel.

If the femtocell utilizes the UL channel, the interference of the secondary signal to the eNB can be expressed as

$$R_s = Q_{\text{su}} d_1^{-\alpha} \quad (16)$$

When a primary transmission is present, the probability that any femtocell user transmits in the UL channel can be expressed as

$$P_{\text{underlay-11}} = P\{Y_1 < \lambda_b, Y_1 < \lambda_1, Y_2 > \lambda_2 \mid H_1\} \quad (17)$$

In this case, the average throughput of the femtocell can be expressed as

$$T_{\text{underlay-11}} = \int_{r_{\min}}^{r_{\max}} W \log_2 \left(1 + \frac{Q_{\text{SU}} r^{-\alpha}}{\sigma^2 + Q_{\text{UE}} d_1^{-\alpha}} \right) f(r) dr \quad (18)$$

Then the probability that the interference to the eNB is beyond the threshold when the femtocell uses the UL channel can be expressed as

$$P_{mb} = P\{R_s > R_b \mid Y_1 < \lambda_b, Y_1 < \lambda_1, Y_2 > \lambda_2 \mid H_1\} = \int_0^\infty \int_0^{(Q_u/r_s)^{1/\alpha}} \frac{Q_m\left(\sqrt{2\frac{Q_{eNB}}{\sigma^2}d_1^{-\alpha}}, \sqrt{\lambda_0}\right)}{\left(1 - Q_m\left(\sqrt{2\frac{Q_{eNB}}{\sigma^2}d_1^{-\alpha}}, \sqrt{\lambda_0}\right)\right)\left(2\frac{Q_{UE}}{\sigma^2}d_2^{-\alpha}, \sqrt{\lambda_2}\right)} dr_s dr_u \quad (19)$$

When primary transmission is absent, the probability that any femtocell user transmits in the UL channel can be expressed as

$$P_{\text{underlay-12}} = P\{Y_1 < \lambda_b, Y_1 < \lambda_1, Y_2 > \lambda_2 \mid H_0\} \quad (20)$$

In this case, the average throughput of the femtocell can be expressed as

$$T_{\text{underlay-12}} = \int_{r_{\min}}^{r_{\max}} W\left(\log_2 + \frac{Q_{SU}r^{-\alpha}}{\sigma^2}\right)f(r)dr \quad (21)$$

The average throughput of the first case is

$$T_{\text{underlay-1}} = P_p P_{\text{underlay-11}} T_{\text{underlay-11}} + (1 - P_p) P_{\text{underlay-12}} T_{\text{underlay-12}} \quad (22)$$

2.3.2 The second case

The second case is that the principal detection in the DL channel indicates the presence of the primary signal while the assisted detection in the UL channel indicates the absence of the primary signal.

As shown in Fig. 3, in this situation, femtocells may occupy the DL channel in an underlay way. But note that the femtocell must carefully evaluate the potential interference in order not to cause unacceptable interference to the UE. That is, the interference R_u from the femtocell to the UE must be beyond a threshold r_u , which is determined by the UE's reception sensitivity and QoS.

The sensing threshold λ_u is used for the HeNB to measure the link between itself and the eNB and make a decision for use the channel or not. If decision statistic $Y_2 < \lambda_u$, the femtocell can utilize the DL channel. On the contrary, if the decision statistic $Y_2 > \lambda_u$, the femtocell cannot utilize the DL channel.

If the femtocell utilizes the DL channel, the interference of the secondary signal to the UE can be calculated as

$$R_u = Q_{su}d_2^{-\alpha} \quad (23)$$

When a primary transmission is present, the probability that any femtocell user transmits in the DL channel can be expressed as

$$P_{\text{underlay-21}} = P\{Y_2 < \lambda_u, Y_1 < \lambda_1, Y_2 < \lambda_2 \mid H_1\} \quad (24)$$

In this case, the average throughput of the femtocell can be expressed as

$$T_{\text{underlay-21}} = \int_{r_{\min}}^{r_{\max}} W\log_2\left(1 + \frac{Q_{SU}r^{-\alpha}}{\sigma^2 + Q_{UE}d_1^{-\alpha}}\right)f(r)dr \quad (25)$$

Then the probability that the interference to the UE is

beyond the threshold when the femtocell utilizes the DL channel is

$$P_{\text{inc}} = P\{R_u > r_u \mid Y_2 < \lambda_u, Y_1 < \lambda_1, Y_2 > \lambda_2 \mid H_1\} = \int_0^\infty \int_0^{(Q_u/r_u)^{1/\alpha}} \frac{Q_m\left(\sqrt{2\frac{Q_{UE}}{\sigma^2}d_1^{-\alpha}}, \sqrt{\lambda_u}\right)}{\left(1 - Q_m\left(\sqrt{2\frac{Q_{UE}}{\sigma^2}d_1^{-\alpha}}, \sqrt{\lambda_u}\right)\right)\left(2\frac{Q_{eNB}}{\sigma^2}d_2^{-\alpha}, \sqrt{\lambda_1}\right)} dr_u dr_s \quad (26)$$

When a primary transmission is absent, the probability that any femtocell user transmits in the DL channel can be expressed as

$$P_{\text{underlay-22}} = P\{Y_2 < \lambda_u, Y_1 < \lambda_1, Y_2 < \lambda_2 \mid H_0\} \quad (27)$$

In this case, the average throughput of the femtocell can be expressed as

$$T_{\text{underlay-22}} = \int_{r_{\min}}^{r_{\max}} W\left(\log_2 + \frac{Q_{SU}r^{-\alpha}}{\sigma^2}\right)f(r)dr \quad (28)$$

The average throughput of the femtocell of the second case is given by

$$T_{\text{underlay-2}} = P_p P_{\text{underlay-21}} T_{\text{underlay-21}} + (1 - P_p) P_{\text{underlay-22}} T_{\text{underlay-22}} \quad (29)$$

Finally, the average throughput of the femtocell is given by

$$T = T_{\text{overlay}} + T_{\text{underlay}} = T_{\text{overlay}} + T_{\text{underlay-1}} + T_{\text{underlay-2}} \quad (30)$$

In this model, the key for success is to keep interference caused by femtocells low enough to ensure a low impact on the performance of an existing macrocell, but there are enough channels for femtocells to achieve high data rates. In the next section, the performance of this model is investigated by system-level simulations.

3 Simulation Results

In this section, the throughput performance of our proposed hybrid access model is evaluated. We also compare the proposed scheme with the conventional cognitive-based overlay scheme.

The simulation parameters are summarized in Tab. 1, which are in line with 3GPP LTE specifications. In our simulation, the overlaying LTE network consists of macrocells and femtocells. We consider one macrocell with a 500 m cell radius, where 10 femtocells and 50 UEs are uniformly distributed in the center macrocell. The network operates in the 2 GHz band with a system bandwidth of 5 MHz. As shown in Tab. 1, macrocell users transmit at an equal fixed power level and have an omni-directional antenna pattern with antenna gain. Each macrocell sector has 10 UEs associated with it on average. UEs are considered to be uniformly distributed in the system. 10 femtocells are uniformly distributed in each macrocell. HUEs are uniformly distributed in a finite circular area around each femtocell (The cell radius is 20 m). Each of

the femtocells operates at an equal fixed power level and an omni-directional antenna pattern with antenna gain.

In the simulation, we adopt the Okumura-Hata model to calculate outdoor path loss and use the COST-231 multi-wall model for indoor path loss. When considering outdoor UEs with respect to a femtocell, a penetration loss of 20 dB is assumed. A closed-access policy is assumed, where only an authorized set of UEs can be associated with a femtocell. In particular, the full load is assumed for each femtocell; thus, each HeNB will select as many channels as possible.

Tab. 1 Simulation parameters

Parameter	Value
Macrocell radius/m	500
Femtocell radius/m	20
eNB antenna gain/dB	14
HeNB antenna gain/dB	9
UE/HUE antenna gain/dB	0
eNB TX power/dBm	46
HeNB TX power/dBm	23
UE/HUE power/dBm	23
Number of UEs	100
Number of HUEs	10
Number of femtocells	10
Thermal noise level/(dBm·Hz ⁻¹)	-174
UE/HUE/HeNB noise figure/dB	5
BS noise figure/dB	7
Lognormal shadowing/dB	8
Penetration loss/dB	20
UL/DL ratio	1:1

We compare the performance of three schemes. The first scheme is to combine the sensing results in the two phases according to the OR rule. The second scheme is to combine the sensing results in the two phases according to the AND rule. The third scheme is to implement our hybrid model.

In Fig. 4, the throughput of the femtocell of the three schemes with various primary transmission probabilities P_p is shown. We can see a clear throughput improvement in our scheme using the hybrid model compared with the scheme using the OR rule, and only a slight throughput decrease in our scheme compared with the scheme using the AND rule. This is because the AND rule scheme utilizes the spectrum in an aggressive way while the OR rule scheme utilizes the spectrum in a conservative way, and the hybrid model utilizes the spectrum according to the spectrum usage and related spatial conditions of macrocell users. Furthermore, we can see that the interference probability of femtocell to macrocell users in Fig. 5 when one time sample is 100 frames and P_p is 0.5. The AND rule scheme causes much more interference than the other two schemes.

From Fig. 4 and Fig. 5, it is shown that the hybrid model can achieve a tradeoff between the conservative

way and the aggressive way. By introducing the hybrid spectrum access model to handle the cross-tier interference, the interference recognition can be well managed and higher capacity can be provided via exploiting the spectrum opportunities efficiently. The throughput of the femtocell is greatly improved with tolerable interference to macrocell users.

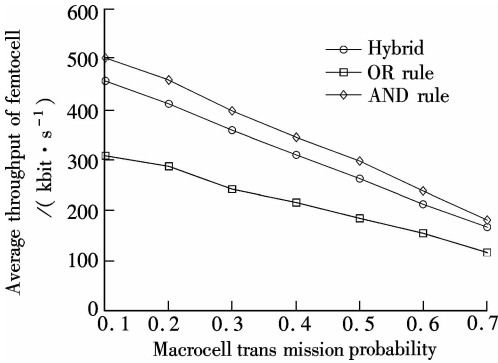


Fig. 4 Average femtocell throughput according to P_p of the three schemes

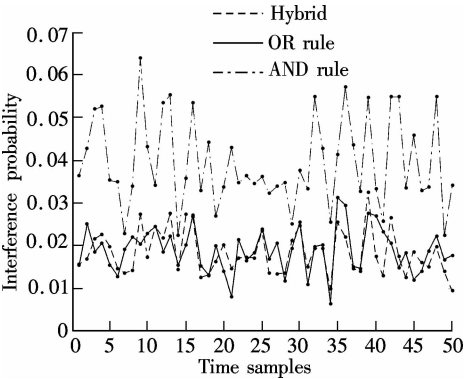


Fig. 5 Interference probability of femtocell to macrocell users

4 Conclusion

In this paper, we present a hybrid underlay/overlay access model for femtocells in the two-tier LTE network. In this model, spectrum sensing is performed in DL channels and the corresponding UL channels, respectively. The favorable usage mode is selected according to the sensing results. Simulation results show that the throughput of the femtocell is greatly improved with tolerable interference to the macrocell.

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认知 Femto 网络中的一种混合式频谱接入模型

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摘要:为了降低因 LTE 系统中布设毫微微小区(家庭基站)而给宏小区用户带来的干扰,采用在毫微微小区中引入认知无线电技术的方法,构建了一种混合式频谱接入模型.毫微微小区通过周期性地感知其无线环境,使之择机接入可用的频段,从而智能地使用频谱资源.对频谱感知分为 2 个阶段,即对宏小区下行链路的主感知和对相应上行链路的辅助感知,基于它们得到的信息,毫微微小区可以灵活地以见缝插针模式或以叠加模式利用频谱.仿真结果表明,在对宏小区的干扰约束限制下,所构建的模型能够带来吞吐量的提升.

关键词:认知无线电;频谱感知;频谱接入;毫微微小区;宏小区

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