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Using TV White Space for Interference Mitigation in LTE Femtocell Networks

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Abstract

The traditional Femtocell shares the same licensed frequency band with Macrocell, thus introducing cross-tier interference. Interference mitigation between the Femtocell and Macrocell is considered to be one of the major challenges in Femtocells Network. In this paper, the released TV spectrum by the digital switchover named TV White Space (TVWS) is proposed to reduce the interference for the LTE Femtocell Network. Based on the combination of cognitive sensing and TVWS, a novel resource allocation scheme is applied to mitigate the interference that Macro users are suffering from nearby Femtocells. A single cell Long Term Evolution (LTE) Femtocell simulator is established to demonstrate the system performance. The cases with traditional resource allocation scheme and the proposed scheme are compared and analysed.

Keywords: Femtocell, TV White Space, Cognitive Sensing, Cross-Tier Interference, Mobile Network

1. Introduction

Cognitive Radio, which was firstly introduced by Joseph Mitola in 1999 [1], is being intensively researched as the key technology for getting access to TV White Space (TVWS). The TVWS is a large portion of vacant spectrum in UHF/VHF bands that are created during the Digital Switchover (DSO) for the higher spectrum efficiency of Digital TV. In a given location there are some vacant channels from guard bands and locally unused TV channels in TV band. These channels could be utilised by low power devices on the basis that not causing interference to TV service. In the UK over 50% of geographical locations are likely to have more than 150MHz of interleaved spectrum (TVWS) [2]. The great attractiveness of TVWS comes from its advantage in the combination of bandwidth and coverage [3]. Using Cognitive Radio (CR) technology to get access to certain licensed bands, like TVWS is being promoted by international organisations, such as Federal Communications Commission (FCC) in US, and recently by Ofcom in UK.

Among many potential applications for the TVWS, one promising application network scenarios is Long Term Evolution (LTE) Femtocell Network, in which it is referred as the HeNB [4]. It is a home base station with short range, low cost, and being linked with the cellular network via a broadband connection; it could offload the traffic in cellular network. Therefore Femtocell is an effective approach to improve the indoor coverage and cell capacity. The main challenge in Femtocell deployment is the cross-tier interference, since traditional Femtocell exploits the same frequency band as the cellular network, cellular users that are located in close proximity to Femtocell BSs may suffer heavy interference from the nearby Femtocells.

Current research of approaches on solving cross-tier interference problem includes: 1) Fractional Frequency reuses and resource partition, in which the main idea is to divide the entire frequency spectrum into several sub-bands, and each sub-band is differentially assigned to sub-area of Macrocell and Femtocells [5]; 2) Power control method focuses on reducing transmission power of HeNBs, the advantage is that base station and HeNB can use the entire bandwidth with interference coordination [6]; 3) Collaborative frequency scheduling. In this approach, the HeNBs receive Macro Users scheduling information from base station, and compare them with their sensing result to find spectrum opportunities [7]; and 4) Cognitive approach uses distributed sensing and shared path-loss information among HeNB neighbours [8]. However, the above approaches are still based on the traditional mobile frequency band, and have limited performance improvement at the expense of complexity. The TVWS was applied to a pure Femtocell Network in our previous study [9].
this paper, we innovatively exploited the TVWS for the LTE Femtocell Network. A novel Cognitive Sensing combined with TVWS resource allocation scheme is proposed to solve the cross-tier interference problem in LTE Femtocell deployment. The improvement of the system performance is demonstrated by simulation results.

The rest of the paper is organised as follows: Part II introduces the system model being studied and the proposed resource allocation scheme in LTE Femtocell Network. Part III presents the simulation model and parameters used for demonstrating the proposed scheme, followed by the analysis on the obtained simulation results in Part IV. Finally, conclusions are drawn in Part V.

2. Using TV White Space For LTE Femtocell Network

A. System Model

1) Network Layout

Our simulator employs a single Macro LTE network with several Femtocells located randomly that represents the actual Femtocell deployment distribution as shown in Figure 1. There are mainly four types of network entities in this scenario, namely Macro Base Station, Macro user, Femto BS and Femto user.

2) Femtocell Deployment Modelling

Femtocell deployment model is built according to 3GPP specification on HeNB suburban deployment modelling [10]. HeNBs are dropped within the macro cell area with a random uniform distribution Figure 2. For each house the HeNB and HeNB UEs are randomly dropped within a specific distance of the centre point of the houses. All Macro users are assumed to be in an indoor environment. A macro UE may be within a HeNB house.

B. Downlink Femto-Macro Interference Scenario

The Macro BS transmission power is typically far larger than the Femto BS transmission power, so that the interference experienced by Macro users is dominated by interference from Macro BS. However, when a Macro user is very close to a Femto BS or even within Femto BS coverage, it experiences high Femto BS interference, as shown in Figure 3. If a Macro user is located in an indoor environment, the signal received from Macro BS is generally very poor due to the wall penetration loss. In traditional Femtocell Network, the Femtocell shares the same spectrum with Macrocell, thus indoor Macro users suffer unacceptable low SINR.

C. Cognitive Sensing combined with TVWS Resource Allocation Scheme

For the proposed interference scenario, an effective approach to mitigate the Cross-Tier Interference would be assigning different spectrum bands for Macrocell and Femtocell respectively. For instance, Femto BS cannot get access to Resource Blocks (RBs) allocated to Macro users in order to avoid the co-channel interference. The traditional way of doing this is using resource partitioning, which is to allocate separate spectrum band for Macrocell and Femtocell. However, this approach is not frequency efficient and it mitigates the interference at the expense of spectrum utilisation.
A Cognitive Sensing combined with TVWS scheme is proposed to exploit the newly opened unlicensed TVWS spectrum for LTE Femtocells, so that to achieve the interference mitigation, while not occupying the spectrum for Macrocell use, and improving spectrum utilisation.

In this scheme, TVWS availability is obtained by Macro BS retrieves information from local TVWS database through our previous study [11]. Macro users will sense nearby Femtocells transmission power. Based on the sensing result, by comparing with pre-defined threshold Macro users will categorised nearby Femtocells as interfering and non-interfering Femtocells. This Information is sent to Macro BS from each Macro user.

The Cognitive Sensing combined with TVWS resource allocation scheme is summarised as follows:

START:

Step1: Cognitive Sensing Stage
  1. All Macro Users sense nearby Femtocells transmission power
  2. Compare the received power with power decision threshold.
     1) If \( P_{r,c} > P_{\text{threshold}} \)
        \( Femto_i \rightarrow \text{Interfering Femtocell List} \)
     2) If \( P_{r,c} < P_{\text{threshold}} \)
        \( Femto_i \rightarrow \text{Non-Interfering Femtocell List} \)
  3. Macro Users send the Interfering Femtocell List as feedback to Macro BS.

Step2: Resource Allocation Stage
  1. Macro BS allocates Resource Blocks (RBs) to Macro Users and Femtocell BSs in the Non-Interfering Femtocell List
  2. Based on the TV White Space availability information from local TVWS Database, Macro BS allocates available TVWS RBs for Femtocells in the Interfering Femtocell List

END

3. Simulation Model and parameters

In this section, we study the performance of the proposed scheme by simulations. The network layout in simulation is illustrated in Figure 4. The big black triangle represents the Macrocell BS, green points are macro users, and blue squares are houses with yards. Small black triangles are Femto BSs, and red points inside the houses are Femtocell users as in Figure 5. Simulation parameters are given in the Table 1.

In the simulation, the path losses for each Macro and Femto users are calculated according to the 3GPP specifications on HeNB [10].

1. Macro BS to Macro User
   a) \( Macro User \ is \ outside \ a \ house \)
   \[ PL(dB) = 15.3 + 37.6 \log_{10} R \text{, } R \text{ in m} \] (1)
   b) \( Macro User \ is \ inside \ a \ house \)
   \[ PL(dB) = 15.3 + 37.6 \log_{10} R + L_{\text{out}} \text{, } R \text{ in m} \] (2)

2. Femto BS to Macro User
   c) \( Macro User \ is \ inside \ the \ same \ house \ as \ Femto BS \)
   \[ PL(dB) = 38.46 + 20 \log_{10} R + 0.7d_{\text{2D, indoor}} + 18.3n(\pi^2 + 0.46) \] (3)
where $R$ is the Tx-Rx separation in meter, $L_{ow}$ is the penetration loss of an outdoor wall, which is 10 dB or 20 dB. $d_{2D}$, indoor is the distance inside the house. $d_{2D}$, indoor is the total distance inside the two houses. $L_{ow,1}$ and $L_{ow,2}$ are the penetration losses of outdoor walls for the two houses.

$$PL(dB) = \max(15.3 + 37.6 \log_{10} R, 38.46 + 20 \log_{10} R)
+ 0.7d_{2D,\text{indoor}} + 18.3n^{(\frac{R+2}{n+1})^{0.46}} + L_{ow}$$

$$PL(dB) = \max(15.3 + 37.6 \log_{10} R, 38.46 + 20 \log_{10} R)
+ 0.7d_{2D,\text{indoor}} + 18.3n^{(\frac{R+2}{n+1})^{0.46}} + L_{ow,1} + L_{ow,2}$$

4. Results and Analysis

The comparison of the improvement in the interference mitigation is carried out first in our simulations. In order to compare with the newly proposed cognitive sensing combined with the TVWS scheme, a traditional resource allocation scheme is also implemented. It is assumed in the traditional resource allocation scheme that all spectrums are shared among Macro and Femto Users. As shown in Figure 6, the vertical axis indicates the interference suffered by Marco users, and horizontal axis is the number of simulation rounds. In the simulation scenario, there are 40 Femtocells with 2 Femto users in each Femtocell and 60 Macrocell users. The red line indicates the traditional all-shared resource allocation scheme, while the blue line is the Cognitive Sensing combined with TVWS scheme.

In Figure 6, it can be seen that when the proposed scheme is applied, the cross-tier interference suffered by Macro users (MUEs) reduced by about 50% compared to that in the traditional scheme. This is because the potential interfering Femtocells in the proposed scheme are allocated with TVWS from Macro BS rather than the same frequency band as Macro Users. Femto BSs have no access to RBs that assigned to Macro users, thus cross-tier interference from Femto BSs to Macro Users is significantly mitigated.

Table 1 Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
</tr>
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<tbody>
<tr>
<td>Femtocells per Macrocell</td>
<td>40</td>
</tr>
<tr>
<td>Femto users per Femtocell</td>
<td>2</td>
</tr>
<tr>
<td>No. of Macro users</td>
<td>100</td>
</tr>
<tr>
<td>Macrocell radius</td>
<td>500 m</td>
</tr>
<tr>
<td>Femtocell radius</td>
<td>12 m</td>
</tr>
<tr>
<td>Carrier Frequency</td>
<td>2000 MHz</td>
</tr>
<tr>
<td>Shadowing standard deviation</td>
<td>8 dB</td>
</tr>
<tr>
<td>Wall Penetration Loss</td>
<td>10dB or 20dB</td>
</tr>
<tr>
<td>Carrier bandwidth</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Total No. of RBs</td>
<td>25</td>
</tr>
<tr>
<td>RB bandwidth</td>
<td>180kHz</td>
</tr>
<tr>
<td>Total Macro BS TX power</td>
<td>46 dBm</td>
</tr>
<tr>
<td>HeNB Tx power</td>
<td>20 dBm</td>
</tr>
<tr>
<td>Minimum distance between UE and cell</td>
<td>$\geq 35$ m</td>
</tr>
<tr>
<td>Min separation UE to HeNB</td>
<td>20 cm</td>
</tr>
<tr>
<td>UE distribution</td>
<td>UEs dropped with uniform density within the indoors/outdoors macro coverage area, subject to a minimum separation to macro and HeNBs.</td>
</tr>
</tbody>
</table>

Figure 7 shows the interference mitigation performance variation when different power decision thresholds are being used, with threshold = -50 dBm, -55 dBm, -60 dBm, -65 dBm and -70 dBm, respectively. As shown in Figure 7, lower threshold leads to higher interference mitigation performance. This is because more interfering Femto BSs can be sensed, and then avoided allocating the same band as Macro users. It can also be seen that Thresholds = -60 dBm, -65 dBm, -70 dBm achieve similar performance. Since lower power decision threshold results in higher requirements on sensing equipment for performing sensing. From the obtained results, an optimised threshold value should be around -60 dBm to -65 dBm in this scenario by taking into account both the performance and cost.
5. Conclusion

In this paper, a resource allocation scheme of using TVWS for LTE Femtocell Network is introduced, which has shown the potential to solve the cross-tier interference in traditional Femtocell deployment. Based on the observation that the TVWS channel is becoming unlicensed and widely available in suburban area, the proposed scheme adopts a Cognitive Sensing combined with TVWS resource allocation scheme for interference mitigation in LTE Femtocell Networks. Simulation results have shown that there is about 50% improvement in mitigating the cross-tier interference compared with traditional resource allocation scheme. From the analysis results, an optimised threshold value for interference mitigation should be around -60 dBm to 65 dBm by taking into account both the performance and cost.

References