Geo-location Database based TV White Space for Interference Mitigation in LTE Femtocell Networks

Fei Peng, Nan Wang, Yue Gao and Laurie Cuthbert
School of Electronic Engineering and Computer Science
Queen Mary University of London
London, UK
fei.peng@eecs.qmul.ac.uk

Xing Zhang
Key Laboratory of Universal Wireless Communication,
Ministry of Education
Beijing University of Posts and Telecommunications
Beijing, P.R. China

Abstract—Interference mitigation between femtocells and the surrounding macrocells is one of the major challenges in femtocell deployment. This paper proposes a system architecture of using TV White Space (TVWS) in LTE femtocell networks, which includes: (i) a Geo-location database to obtain locally available TVWS information, and (ii) a new resource allocation scheme using the locally available TVWS to mitigate the downlink cross-tier interference between macrocell users and nearby femtocells. A two-tier multi-femtocell simulator is established to demonstrate the system performance. Simulations at different scenarios are conducted to compare the performance of the traditional all-shared resource allocation scheme, dynamic resource partitioning scheme and the proposed scheme. Simulation results show that the proposed scheme has better downlink interference mitigation performance in comparison with the other two schemes.

Keywords—Femtocell, TV White Space, Geo-location Database, Cross-Tier Interference, Mobile Networks

I. INTRODUCTION

Recently, Federal Communications Commission (FCC) in US has approved rules that allow unlicensed devices to operate in TV White Spaces (TVWS) [1], while the Office of Communications (Ofcom) in UK also published statements on allowing coexistence of the licensed and unlicensed users in TVWS at some geographical regions [2][3]. TVWS resource is abundant. For instance, in UK over 50% of geographical locations are likely to have more than 150MHz of TVWS [4]. The attractiveness of TVWS not only comes from the additional bandwidth it brings, but also from good coverage performance, since signals in TV band can penetrate buildings more easily than higher spectrum frequencies [5].

One promising application of TVWS is the Long Term Evolution (LTE) femtocell networks. A LTE femtocell station is also referred to as the Home eNode B (HeNB) [6]. It is an effective approach to improving the indoor coverage and cell capacity. The major challenge in current femtocell deployment is the cross-tier interference between macrocell users and nearby HeNBs. Since current femtocell exploits the same frequency band as the cellular networks, macrocell users that are located in close proximity to HeNBs may suffer heavy cross-tier interference from those femtocells.

Previous research on reducing cross-tier interference includes: (i) Fractional frequency reuse and resource partition, in which the main idea is to divide the entire frequency spectrum into several sub-bands, and each sub-band is differently assigned to a sub-area of the macrocell and femtocells [7]; (ii) Power control that focuses on reducing the transmit power of HeNBs, the advantage being that the base station and the HeNBs can use the entire bandwidth with interference coordination [8]; (iii) collaborative frequency scheduling where the HeNBs receive Macro UEs scheduling information from the base station, and compare them with their sensing results to find spectrum opportunities [9].

The above approaches are based on the licensed cellular frequency band, and have limited performance improvement at the expense of complexity. However, to the best of author’s knowledge, the study of using TVWS to mitigate the interference in LTE femtocell networks has not been reported in the literature. TVWS has been applied to a simplified femtocell network in our previous study [10]. In this paper, a practical system architecture for using TVWS in LTE femtocell networks is proposed. It includes a Geo-location database method designed to obtain locally available TVWS information, and a resource allocation scheme to use the locally available TVWS to address the downlink cross-tier interference problem in the LTE femtocell networks. A LTE multi-femtocell simulator is established to demonstrate the proposed system architecture. The simulation results show that the proposed scheme has better performance in reducing the downlink interference suffered by Macro UEs, compared with the traditional all-shared scheme and dynamic resource partitioning scheme. The performance is even better when more femtocells are deployed.

The rest of the paper is organised as follows: Section II introduces the proposed system architecture. Section III presents the proposed Geo-location database. The new resource allocation scheme for cross-tier interference
mitigation in LTE femtocell networks is described in Section IV. Section V shows the simulation model and parameters, followed by the analysis on the obtained simulation results in Section VI. Finally, conclusions are drawn in Section VII.

II. SYSTEM MODEL

A. Research Scenario

The scenario considered in this paper is a LTE femtocell network in the suburban area. We consider the “closed-access femtocell” scheme that restricts the use of the femtocell to users explicitly approved by the owner [11]. In other words, the femtocell only serves femtocell users and is not open to Macro users. It is also the most common scenario where severe cross-tier interference happens [12]. Femtocells are located randomly in the macrocell as shown in Fig. 1. There are four types of network entities in this scenario, namely eNB, Macro UE (MUE), HeNB and Femto UE (FUE). When a Macro UE is very close to a HeNB or even within the HeNB’s coverage, it experiences severe interference from nearby HeNB operating in the co-channel. As shown in Fig. 1, a MUE is far away from the macrocell eNB and is located around a HeNB’s coverage edge; if the HeNB uses the same frequencies as the MUE, then this MUE will experience severe cross-tier interference, resulting in poor useful signal reception.

B. Proposed System Architecture

Fig.2 shows the proposed system architecture of using TVWS for interference mitigation in LTE femtocell networks:

- **Central Controller** is located in the eNB and conducts the resource allocation.
- **Geo-location Database** is co-located with the central controller and stores TVWS information.
- **HeNBs** are located randomly in the macrocell area.
- **Users** include Macro UEs and Femto UEs.

III. PROPOSED GEO-LOCATION DATABASE

In our proposed system, a Geo-location database is connected with the eNB. The database is designed to obtain the locally available TVWS channel information, and protect the primary TV system users from harmful interference due to the secondary use of TVWS. The database can provide the TVWS information to eNB for resource allocation as introduced later.

The Geo-location database is built according to the 81 TV sites plan in UK [13], including each of the DTV station’s location, operational channel and transmit power. The TV service protection requirements are also implemented in the database, as shown in TABLE [14]. The co-channel interference protection D/U (Desired signal/Undesired signal) ratio is implemented in the database to determine whether the operational channel bands of the DTV base station can be available for secondary use in a given location.

<table>
<thead>
<tr>
<th>Type of service</th>
<th>Channel Offset</th>
<th>Interference Protection D/U Ratio (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog TV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Adjacent</td>
<td>-14</td>
</tr>
<tr>
<td></td>
<td>Co-channel</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Upper Adjacent</td>
<td>-17</td>
</tr>
<tr>
<td>Digital TV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Adjacent</td>
<td>-28</td>
</tr>
<tr>
<td></td>
<td>Co-channel</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Upper Adjacent</td>
<td>-26</td>
</tr>
</tbody>
</table>

In this paper, LTE femtocell network is the application to use the Geo-location database to obtain locally available TVWS information. TVWS can be shared by many different applications by using the Geo-location database. This can be achieved by updating the database with TVWS usages of different applications, ensuring there is no collision between these TVWS usages.

In the Geo-location database, the local location will be interpreted in the form of national grid reference coordinates (NGR) format. Based on the TV station locations and their operation channels information from the 81 TV sites plan, our Geo-location database can calculate the available TVWS channels for a specific location according to the minimum distance to DTV’s coverage edge within which no secondary transmission would be allowed [15].

Moreover, the database can also calculate the associated maximum allowable transmit power $EIRP_{max}$.
for each TVWS channel. As stated in [16], the EIRP can be calculated by Equation (1), where $d$ is the distance between the point and the source, $\eta$ is the intrinsic impedance. In order to obtain the $EIRP_{\text{max}}$, firstly we need to calculate $E_{\text{Edgemax}}$, which is the maximum allowable E-field strength of secondary use at the affected DTV station coverage edge, and $d_{Bp}$, the “Break-Point Distance”.

$$EIRP_{\text{max}} = \frac{4\pi d^4 E_{\text{Edgemax}}^2}{d_{Bp} \eta}$$  \hspace{1cm} (1)

$E_{\text{Edgemax}}$ can be calculated based on the required Interference Protection D/U Ratios of TV service at the edge of DTV protected contour, as shown in Equation (2), where $E_{TV}$ is the E-field strength of DTV signal at the its protection contour, $(D/U)_{cc}$ and $(D/U)_{ac}$ are the maximum tolerable co- and adjacent channel interference protection ratios for the affected service. $F/B$ represents the 14dB front-to-back ratio for the affected TV receiver antenna.

$$E_{\text{Edgemax}} = \min\{ (E_{TV} - (D / U)_{cc} + F / B), \ (E_{TV} - (D / U)_{ac} + F / B) \}$$  \hspace{1cm} (2)

The “Break-Point Distance” $d_{Bp}$ is used to differentiate the square-law and forth law for the two-ray propagation model, and can be calculated according to Equation (3). Where $K$ is a predefined constant (ranges from between 0.5 to 8), $\lambda$ is the wavelength (in meters), $H_{TX}$ and $H_{RX}$ are the heights of the TVWS device transmit and incumbent TV receiver antennas respectively (in meters).

$$d_{Bp} = KH_{TX}H_{RX} / \lambda$$  \hspace{1cm} (3)

TABLE shows an example result of the Geo-location database by inputting a location (NGR: NS595655) in Glasgow, UK. As shown in the result, there are 9 TVWS channels available in that location with different maximum allowable transmit power. The details of the designed database can be found in our previous study [17].

TABLE II An example result of the Geo-location database

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>30</th>
<th>42</th>
<th>45</th>
<th>48</th>
<th>49</th>
<th>51</th>
<th>52</th>
<th>55</th>
<th>56</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Allowable EIRP (watts)</td>
<td>4</td>
<td>0.128</td>
<td>0.119</td>
<td>4</td>
<td>0.108</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

IV. PROPOSED RESOURCE ALLOCATION SCHEME

In our proposed system architecture of using TVWS for interference mitigation in femtocell networks, the eNB can obtain the available TVWS information in its coverage area from the co-located Geo-location database, and schedule the resource allocation. A new resource allocation scheme using the obtained TVWS is proposed to reduce the downlink cross-tier interference between femtocells and nearby MUEs. The basic idea of the scheme is to assess which of the femtocells are causing interference to one or more macrocell users at a given point, and then those femtocells are temporarily allocated with the obtained TVWS resource to avoid their potential interference on nearby Macro users.

The scheme consists of two steps, which are the femtocell classification and resource allocation. The classification step relies on the measurement reports by the Macro UEs. It is assumed that MUEs can arbitrarily detect the Reference Signal Received Power (RSRP) from eNB (as desired signal) and each HeNB (as interference) in the downlink. Depending on the received RSRP signal power from eNB and HeNBs, a MUE can calculate the receiving SIRs. If the receiving SINR at MUEs is lower than the pre-defined threshold $\nu_{th}$, the related femtocells are categorized as interfering, otherwise non-interfering. The Macro UE will add the interfering femtocells IDs into its interference set $\text{Set}_i$ and send this information to the eNB for further processing. All the information is supposed to be transferred through the backhaul or over the air interface with negligible overhead. Then the eNB will perform resource allocation according to the MUE measurements reports and TVWS information from Geo-location database.

The procedure of the proposed resource allocation scheme is summarised in TABLE. In the description of scheme, $m$ is the index of a MUE in the macrocell. $i$ is the index of a HeNB in the macrocell. $SINR_{m,i}$ denotes the SINR of MUE $m$ when signal $P_m$ from eNB is regarded as the desired signal and signal $I_i$ from HeNB $i$ as the interference.

TABLE III Procedure of the proposed resource allocation scheme

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Every MUE $m$ estimates the Reference Signal Received Power (RSRP) from eNB and each HeNB in the downlink.</td>
</tr>
<tr>
<td>2.</td>
<td>Compute the $SINR_{m,i}$ of MUE $m$ for every HeNB $i$, by using the received RSRP signal $P_m$ from eNB as desired signal and RSRP signal $I_i$ from HeNB $i$ as interference. $\sigma^2$ represents the thermal noise.</td>
</tr>
<tr>
<td>3.</td>
<td>Compare the $SINR_{m,i}$ at MUE $m$ with the threshold $\nu_{th}$.</td>
</tr>
<tr>
<td>4.</td>
<td>Femtocell $i$ is marked by MUE $m$ as non-interfering femtocell if the $SINR_{m,i}$ is larger than the threshold, otherwise, it is marked as an interfering femtocell to that MUE $m$.</td>
</tr>
<tr>
<td>5.</td>
<td>Each MUE $m$ sends its femtocell interference information to eNB.</td>
</tr>
<tr>
<td>6.</td>
<td>The Central Controller in eNB will sort the interfering and non-interfering femtocells results from all MUEs reports, femtocells which are marked as interfering by one or more MUEs will be regarded as interfering femtocells.</td>
</tr>
<tr>
<td>7.</td>
<td>Based on the obtained TV White Space information from co-located Geo-location database. The central controller will allocate TVWS Resource Blocks (RBs) to interfering femtocells in a fair scheduling manner and allocate mobile spectrum RBs to non-interfering femtocells and MUEs in a fair scheduling manner.</td>
</tr>
</tbody>
</table>

START

Step1: Femtocell Classification

1. Every MUE $m$ estimates the Reference Signal Received Power (RSRP) from eNB and each HeNB in the downlink.

2. Compute the $SINR_{m,i}$ of MUE $m$ for every HeNB $i$, by using the received RSRP signal $P_m$ from eNB as desired signal and RSRP signal $I_i$ from HeNB $i$ as interference. $\sigma^2$ represents the thermal noise.

\[
SINR_{m,i} = \frac{P_m}{I_i + \sigma^2}
\]

3. Compare the $SINR_{m,i}$ at MUE $m$ with the threshold $\nu_{th}$.

4. Femtocell $i$ is marked by MUE $m$ as non-interfering femtocell if the $SINR_{m,i}$ is larger than the threshold, otherwise, it is marked as an interfering femtocell to that MUE $m$.

5. Each MUE $m$ sends its femtocell interference information to eNB.

Step2: Resource Allocation

6. The Central Controller in eNB will sort the interfering and non-interfering femtocells results from all MUEs reports, femtocells which are marked as interfering by one or more MUEs will be regarded as interfering femtocells.

7. Based on the obtained TV White Space information from co-located Geo-location database. The central controller will allocate TVWS Resource Blocks (RBs) to interfering femtocells in a fair scheduling manner and allocate mobile spectrum RBs to non-interfering femtocells and MUEs in a fair scheduling manner.

END
According to the proposed scheme described above, the system operating sequence is illustrated in Fig. 3.

![Fig. 3. System operating sequence chart](image)

**V. SIMULATION MODEL AND SETUP**

In this section, the proposed system including the Geo-location database and resource allocation scheme is simulated in a two-tier multi-femtocell scenario based on LTE-A standards using MATLAB to demonstrate its performance [18]. It is assumed that the macrocell is located around the campus of Queen Mary, University of London. Femtocell deployment is modelled according to 3GPP specification on HeNB suburban deployment model [19]. HeNBs are randomly dropped within the houses. Macro/Femto UEs are dropped with uniform density within the outdoors/indoors macrocell coverage area, subject to a minimum separation to eNB/HeNBs. Simulation parameters are given in TABLE IV. 

**TABLE IV Simulation parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femtocells per macrocell</td>
<td>5</td>
</tr>
<tr>
<td>Femto UEs per femtocell</td>
<td>2</td>
</tr>
<tr>
<td>Number of Macro UEs</td>
<td>50</td>
</tr>
<tr>
<td>Macrocell Radius</td>
<td>288m</td>
</tr>
<tr>
<td>Femtocell Radius</td>
<td>12m</td>
</tr>
<tr>
<td>Wall Penetration Loss</td>
<td>10dB/20dB</td>
</tr>
<tr>
<td>System Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>Total No. of RBs</td>
<td>50</td>
</tr>
<tr>
<td>RB Bandwidth</td>
<td>180kHz</td>
</tr>
<tr>
<td>Total eNB Transmit Power</td>
<td>46dBm</td>
</tr>
<tr>
<td>HeNB Transmit Power</td>
<td>20dBm</td>
</tr>
<tr>
<td>Thermal Noise</td>
<td>-174dBm/Hz</td>
</tr>
<tr>
<td>SINR Threshold</td>
<td>-8dB</td>
</tr>
<tr>
<td>Minimum Distance between UE and eNB</td>
<td>35m</td>
</tr>
<tr>
<td>Minimum Separation between UE and HeNB</td>
<td>20cm</td>
</tr>
</tbody>
</table>

In the simulation, the path losses for each UE (Macro UE and Femto UE) are calculated according to path loss models in the 3GPP HeNB specification [18].

1. **eNB to UE**
   a) UE is outside a house
   \[
   PL(dB) = 15.3 + 37.6 \log_{10} R 
   \]  
   (4)

2. **HeNB to UE**
   a) UE is inside the same house as HeNB
   \[
   PL(dB) = 38.46 + 20 \log_{10} R + 0.7d_{2D,\text{indoor}} + 18.3n^{0.5} + L_{\text{ew}} 
   \]  
   (6)

b) UE is outside a house
   \[
   PL(dB) = \max(15.3 + 37.6 \log_{10} R, 38.46 + 20 \log_{10} R) 
   \]  
   (7)

c) UE is inside a different house
   \[
   PL(dB) = \max(15.3 + 37.6 \log_{10} R, 38.46 + 20 \log_{10} R) 
   \]  
   (8)

where \( R \) is the Tx-Rx separation in meters, \( L_{\text{ew}} \) is the penetration loss of an outdoor wall, which is 10dB or 20dB. \( d_{2D,\text{indoor}} \) is the distance inside the house in meters. \( n \) is the number of penetrated floors. \( L_{\text{ew,1}} \) and \( L_{\text{ew,2}} \) are the penetration losses of outdoor walls for the two houses.

**VI. RESULTS AND ANALYSIS**

**TABLE** shows the available TVWS information results returned from the Geo-location database introduced in section III, when the simulated location is Queen Mary University of London, post code E1 4NS (National Grid Reference: TQ360823). As we can see from TABLE V, there are 4 TVWS channels (channel 29, 50, 56, 58) available at this location. The maximum allowable power of channel 29, 50, 58 is 4W, while for channel 56 it is 0.315W, which is still sufficient for femtocell, whose transmit power is just about 0.1W.

**TABLE V Available TVWS information results from Geo-location database (Simulated location: Queen Mary, University of London)**

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>NGR Number of location: TQ360823</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>Maximum Allowable EIRP(watts)</td>
</tr>
<tr>
<td>50</td>
<td>4.000</td>
</tr>
<tr>
<td>56</td>
<td>0.315</td>
</tr>
<tr>
<td>58</td>
<td>4.000</td>
</tr>
</tbody>
</table>

In order to benchmark the proposed resource allocation scheme, a traditional resource allocation scheme is implemented where the entire spectrum is shared between Macro UEs and femtocells. A dynamic resource partitioning (DRP) scheme introduced in [20] is also implemented, where the idea is to deny HeNBs access to RBs which have been allocated to nearby Macro UEs, so that to eliminate the interference originating from the interfering HeNBs. In simulating the traditional and DRP schemes, the same parameters as those used in the proposed scheme are employed. The cumulative distribution function (CDF) of downlink interference for Macro UEs obtained from the
simulation is shown in Fig. 4. The dashed line indicates the traditional all-shared resource allocation scheme, and the solid line indicates the DRP scheme, while the dashed line with solid circles is the proposed scheme. In this case, there are 5 femtocells in macrocell area. It can be seen that the proposed scheme outperforms the traditional one and the DRP one. It reduces the interference that Macro UEs experience by more than 3dB and 2.5dB compared with the traditional and DRP respectively (at the 70% percentile of the CDF diagram). This is because the potential interfering femtocells in the proposed scheme are allocated with TVWS RBs from the eNB rather than RBs in the same frequency band as Macro UEs. HeNBs of these femtocells have no access to RBs that assigned to Macro UEs, thus cross-tier interference from HeNBs to Macro UEs is significantly mitigated.

Fig. 4. Interference comparisons of traditional, DRP and proposed schemes with 5 femtocells

We also studied the effect of different macrocell cell sizes on interference mitigation performance. In this case, it is assumed that there are 10 femtocells in the macrocell area. As shown in Fig. 6, the interference experienced by the Macro UEs becomes smaller in a larger macrocell. This is due to the larger distance between HeNB and Macro UEs. From Fig. 6 we can observe that in a macrocell with a radius of 144m, the proposed scheme reduces the interference experienced compared with the traditional scheme by about 10dB at the 70% percentile of the CDF diagram; while for a macrocell with a radius of 288m, it reduces the interference by about 4dB. And for a macrocell with a radius of 577m, it reduces the interference by about 4dB. This indicates that when the macrocell is small, the proposed scheme achieves a larger improvement against the traditional scheme, and the Macro UEs experience much less interference.

Fig. 6. Interference comparison with different macrocell radii

Fig. 5 shows the interference mitigation performance variation with different numbers of femtocells in comparison with the traditional scheme. It can be observed that as the number of femtocells increases, e.g. from 10, 15 to 20 (each femtocell has 2 FUEs), the downlink interference experienced by Macro UEs also increases, which can be seen in the diagram that the CDF curve is moving right as the femtocell number increases. When the proposed scheme is applied, as the femtocell number increases by the step size of 5, the interference increases by about 2dB on average at the 70% percentile in Fig. 5, which is smaller than with the traditional scheme (about 4dB). So as the number of femtocells increases, the proposed scheme is better than the traditional scheme in limiting the increase of interference incurred (reduced by about 2dB on average). This means that when there are more femtocells deployed, Macro UEs experience much less cross-tier interference if the proposed scheme is implemented.

Fig. 5. Interference comparisons with different number of femtocells

We also studied the effect of different macrocell cell sizes on interference mitigation performance. In this case, it is assumed that there are 10 femtocells in the macrocell area. As shown in Fig. 6, the interference experienced by the Macro UEs becomes smaller in a larger macrocell. This is due to the larger distance between HeNB and Macro UEs. From Fig. 6 we can observe that in a macrocell with a radius of 144m, the proposed scheme reduces the interference experienced compared with the traditional scheme by about 10dB at the 70% percentile of the CDF diagram; while for a macrocell with a radius of 288m, it reduces the interference by about 4dB. And for a macrocell with a radius of 577m, it reduces the interference by about 4dB. This indicates that when the macrocell is small, the proposed scheme achieves a larger improvement against the traditional scheme, and the Macro UEs experience much less interference.

Fig. 6. Interference comparison with different macrocell radii
VII. CONCLUSION

In this paper, a Geo-location database based system architecture with a new resource allocation scheme was proposed. This system architecture used TVWS to address the downlink cross-tier interference problem in LTE femtocell networks. Simulation results showed that the proposed scheme reduced the downlink interference suffered by Macro UEs by more than 3dB and 2.5dB (at the 70% percentile of the CDF diagram), compared with the traditional all-shared scheme and the dynamic resource partitioning scheme respectively. The performance of the proposed scheme was even better when more femtocells were deployed. Moreover, the impact on interference mitigation performance of different numbers of femtocells and different macrocell sizes were also analysed by investigating different scenarios. Results showed that the proposed scheme had better performance in the scenarios of dense femtocell distribution and small macrocells. In conclusion, the proposed Geo-location database based system architecture with the new resource allocation scheme can greatly improve service to Macro UEs lying in the proximity of femtocells by utilizing the locally available TV White Space.

REFERENCES


