Self-Organizing Network-based Cell Size Adaption and Traffic Adaptive eICIC in LTE-A HetNets

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The Long Term Evolution-Advanced (LTE-A) heterogeneous network (HetNet), which can increase the capacity of LTE-A, is composed of high power macrocells and low power picocells. However, unbalanced loading between macro and pico cells and inter-cell interference problems are two major performance bottlenecks in LTE-A heterogeneous networks (HetNets). We propose Self-Organizing Network (SON)-based Cell Size Adaption (SCSA) for load balancing between macro and pico cells and mitigating the inter-cell interference problem. We also propose Traffic Adaptive enhanced Inter-Cell Interference Coordination (TAeICIC) to further mitigate the inter-cell interference problem. The proposed SCSA uses dynamic multi-threshold load management to dynamically set the transmission power of each pico evolved NodeB (eNB) by adjusting the pilot power. In addition, the proposed TAeICIC utilizes a scheduling metric, proportional-fair (PF), which is the estimated throughput based on the channel quality indication (CQI) reported by a user equipment (UE) divided by the estimated long term average throughput achieved by the UE, to dynamically allocate an appropriate number of Almost Blank Subframes (ABSs) in each ABS period in a macrocell so as to mitigate the interference from the macrocell to its adjacent picocells. Simulation results show that the proposed SCSA+TAeICIC is better than DI, PF-ABS, and IL-ABS in terms of average throughput of eNBs (15.43%, 25.66%, 31.49% improvement, respectively), average throughput of UEs (16.25%, 29.39%, 39.38% improvement, respectively), average radio interface delay of UEs (81.01%, 84.97%, 86.52% improvement, respectively), and average energy consumption per pico eNB (54.38% improvement for each related method). Therefore, the proposed SCSA+TAeICIC can significantly enhance the Quality of Experience (QoE) of mobile users and reduce the operating expenditure (OPEX) of the operators in LTE-A HetNets.

Keywords: enhanced inter-cell interference coordination (eICIC), HetNet, LTE-A, load balancing, self-organizing network (SON)

1. INTRODUCTION

Wireless data traffic has seen prolific growth in recent years because the use of smart handheld devices and new emerging services are widespread, such as real-time video streaming and multimedia file sharing. Therefore, the future wireless cellular network must be designed to satisfy these bandwidth hungry services [1-3]. In order to enhance the capability of the cellular network, an operator needs to pay a large amount of money to upgrade and maintain its cellular network. In addition, users are not willing to pay more money to the operator to improve the cellular network’s capability. Thus,
how to reduce the capital expenditure (CAPEX) and operating expenditure (OPEX) has become a crucial issue for the operator. A self-organizing network (SON), as a promising solution for both operators and users, has been proposed to effectively reduce CAPEX and OPEX by minimizing human involvement in networking processes and optimizing network capacity, coverage, and service quality [4, 5]. The SON consists of three phases: self-configuration, self-optimization and self-healing [6]. Self-configuration includes pre-operational functions such as registering with the network, parameter setting, and software downloading [6]. Self-optimization includes load balancing, coverage and capacity optimization, and inter-cell interference coordination [3]. Self-healing includes cell outage detection and compensation [3]. In this paper, we focus on all the above three aspects of self-optimization.

With the rapid growth in wireless data, we need to make the available radio spectrum as spectrally efficient as possible. The Long Term Evolution-Advanced (LTE-A) heterogeneous network (HetNet) is a promising solution to expand capacity and to efficiently utilize the radio spectrum of the mobile network [2]. The LTE-A HetNet, which consists of high power macrocells and low power picocells, as shown in Fig. 1, is deployed in a high user equipment (UE) density area, so called a hot spot area, so as to increase the capacity of the LTE-A [7, 8]. Note that the notation CRE in Fig. 1 represents a cell range extension region, which will be described later. However, LTE-A HetNets encounter two problems. First, since low power picocells share the same frequency spectrum with high power macrocells, the performance of low power picocells may be severely interfered by high power macrocells. Second, a UE by default connects to an evolved NodeB (eNB) which has stronger reference signal power (RSP). That is, UEs will connect to macro eNBs in most locations, because a macro eNB has stronger RSP than a pico eNB. This may result in underutilized pico eNBs and defeat the purpose of deploying pico eNBs. In Fig. 1, the UEs not close to picocells may be interfered by the macrocell in the downlink and may connect to the macrocell because of the macrocell’s high power. In order to solve the above problems, the 3rd Generation Partnership Project (3GPP) proposed the enhanced inter-cell interference coordination (eICIC) known as the
time domain ICIC [9] to protect the downlink behavior of the picocell. In the eICIC, each macro eNB remains silent during the Almost Blank Subframes (ABS) over which pico eNBs can transmit in reduced interference. Moreover, 3GPP also proposed Cell Selection Bias (CSB) [10], which can create a CRE region for a picocell, to increase the reference signal received power (RSRP) of UEs received from the picocell so as to offload some UEs from the macrocell to the picocell. In addition to the CSB, 3GPP also proposed an SON solution [11] to adjust the transmission power of an eNB. By increasing the transmission power of a pico eNB, some UEs can be offloaded from a macrocell to the adjacent picocell.

In this paper, we utilize the SON to create a CRE region for a picocell since increasing the transmission power of a pico eNB can mitigate the interference from the corresponding macro eNB to those UEs located in the CRE of the pico eNB. Therefore, we propose an SON-based Cell Size Adaption (SCSA) for load balancing and mitigating the inter-cell interference problem and propose Traffic Adaptive Enhanced Inter-cell Interference Coordination (TAeICIC) scheme to further mitigate the inter-cell interference problem in LTE-A HetNets. The objectives of this paper are conquering the above two problems of LTE-A HetNets by achieving load balancing between a macrocell and adjacent picocells and reducing the interference from the macrocell to the picocells so as to increase the throughput performance of each eNB and each UE and to decrease the radio interface delay experienced by each UE.

The rest of this paper is organized as follows. Section 2 briefs background and related work. Section 3 describes an LTE-A HetNet architecture. Section 4 presents the proposed SCSA+TAeICIC. In section 5, an analytic model is described. Performance evaluation results are discussed in section 6. Section 7 concludes this paper.

2. BACKGROUND AND RELATED WORK

2.1 Enhanced Inter-cell Interference Coordination (eICIC) [9]

In the eICIC, each macro eNB remains silent during the ABS over which a pico eNB can transmit with low interference so as to protect the downlink transmission of the pico eNB. The macro eNB can only send control signals, which only occupy a small fraction of an Orthogonal Frequency Division Multiple Access (OFDMA) subcarrier, during the ABS. Fig. 2 shows the frame structure of the eICIC [9].
2.2 Cell Selection Bias (CSB) [10]

Assume $\alpha_i$ is the CSB of a cell and $p_i$ is the RSRP (in dBm) from cell $i$, as measured by a UE. Note that the cell can be either a macrocell or a picocell. Then, the UE associates with cell $k$ according to Eq. (1)

$$k = \arg \max_i (p_i + \alpha_i).$$

Thus, by assigning a larger (smaller) CSB to picocells compared to macrocells, we can ensure more (fewer) UEs to connect to picocells. The bias values are broadcast by cells to help UEs to select an appropriate cell.

2.3 Related Work

Ma et al. [12] proposed an SON load balancing mechanism based on the reinforcement learning (RL) to dynamically change the coverage areas of relay nodes in a multi-hop cellular network environment. Note that Ma et al. [12] focuses on macro eNBs mixed with relay nodes instead of pico eNBs. Erlinghagen et al. [7] used an eNB’s utility to determine the CSB of the eNB for each UE to select an appropriate eNB (macro or pico) so as to increase the resource utilization of a pico eNB and to determine the number of ABSs a pico eNB can use. In addition, it utilizes the CSB to create the CRE of a pico eNB. However, adopting the CSB to adjust the RSRP has the following two disadvantages. First, UEs located in the CRE of a pico eNB still have strong interference from the corresponding macro eNB. Second, UEs need to perform additional computation in the CSB scheme, which may increase the power consumption of UEs. Soret and Pedersen [13] proposed an instantaneous-load-based algorithm (IL-ABS) which allocates ABSs according to the loads of macro and pico eNBs. They also proposed a proportional-fair-based algorithm (PF-ABS) which increases or decreases one ABS allocated in an ABS period (as shown in Fig. 2) according to the average throughput achieved by UEs and their instantaneous channel conditions. In [13], it showed that PF-ABS has better performance than IL-ABS. However, in [13], it did not propose any SON-based or CSB mechanism that can achieve load balancing among macro and pico eNBs. The above problems of the related work motivate us to propose the SCSA to adaptively change the transmission power of a pico eNB so as to mitigate the inter-cell interference problem from a macro eNB to its adjacent pico eNBs and achieve load balancing between macro and pico eNBs, and to propose the TAeICIC to allocate ABSs more efficiently so as to further mitigate the inter-cell interference. Table 1 summarizes the differences between the proposed SCSA+TAeICIC and the three related works.

<table>
<thead>
<tr>
<th>Method</th>
<th>Design focus</th>
<th>CRE criterion</th>
<th>Small cell</th>
</tr>
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<tbody>
<tr>
<td>Ma et al. [12]</td>
<td>Proposed an SON load balancing mechanism based on RL to dynamically change the coverage areas of relay nodes in a multi-hop cellular network environment.</td>
<td>SON (adjust relay node’s transmission power)</td>
<td>Relay node</td>
</tr>
</tbody>
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Table 1. (Cont’d) Comparison of the proposed SCSA+TAeICIC with three related works.

<table>
<thead>
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<th></th>
<th>Erlinghagen et al. (Di) [7]</th>
<th>Soret and Pedersen (IL-ABS and PF-ABS) [13]</th>
<th>Proposed SCSA+TAeICIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Use the eNB’s utility to determine the CSB for each UE to select an appropriate eNB and the number of ABSs a pico eNB can use.</td>
<td>Proposed IL-ABS which allocates ABSs according to the load of macro and pico eNBs and proposed PF-ABS which increases or decreases one ABS allocated in an ABS period according to the average throughput achieved by UEs and their instantaneous channel conditions.</td>
<td>Proposed SCSA which uses dynamic multi-threshold load management to dynamically adjust the transmission power of a pico eNB and proposed TAeICIC to allocate an appropriate number of ABSs in an ABS period according to the average throughput achieved by UEs and their instantaneous channel condition.</td>
</tr>
<tr>
<td></td>
<td>CSB (adjust UE’s RSRP)</td>
<td>N/A</td>
<td>SON (adjust pico eNB’s transmission power)</td>
</tr>
<tr>
<td></td>
<td>Pico</td>
<td>Pico</td>
<td>Pico</td>
</tr>
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3. LTE-A HETNET ARCHITECTURE

Fig. 3 shows the proposed LTE-A HetNet architecture which has three picocells in a macrocell. The macro/pico eNBs communicate with each other by the X2 interface. In this paper, we suppose that a macro eNB’s coverage area cannot be changed so as to avoid the coverage holes problem and the pico eNB’s coverage can be dynamically changed to relieve the high loading problem of macro eNBs and to achieve load balancing among macro and pico cells.

Fig. 3. Proposed LTE HetNet architecture.
A UE’s association strategy is based on the RSRP. The RSRP is measured by the UE over the cell-specific Reference Signals (RSs) within the measurement bandwidth over a measurement period \[14\]. Note that the RSRP is a type of signal strength measurement and is indicative of the cell coverage \[14\]. The RSRP is calculated based on the RSP, as shown in Eq. (2) \[12\]:

\[
\text{RSRP}_y = \text{RSP}_i - PL_{ij} + SF_{ij}.
\]

where \(\text{RSP}_i\) is the RSP transmitted by the \(i\)th eNB, \(\text{RSRP}_{ij}\) is the corresponding RSRP measured by the \(j\)th UE, \(PL_{ij}\) is the path loss between the \(i\)th eNB and the \(j\)th UE, and \(SF_{ij}\) is the shadow fading between the \(i\)th eNB and the \(j\)th UE. A UE always associates with the eNB which has the highest RSRP measurement. Thus, adjusting the RSP, which can modify the RSRP measured by a UE and affect the UE association decision, can redistribute the network load \[12\].

The loading of the \(i\)th pico eNB at time \(t\) can be defined as the utilization of the \(i\)th pico eNB, as shown in Eq. (3):

\[
\sigma_{\text{pico}-i, t} = \frac{N_{\text{pico}-i, t}}{N_{\text{pico-capacity}}}
\]

where \(N_{\text{pico}-i, t}\) and \(N_{\text{pico-capacity}}\) represent the number of UEs being served by the \(i\)th pico eNB at time \(t\) and the total number of UEs can be served by a pico eNB, respectively. Note that the loading of the \(i\)th pico eNB at time \(t\), \(\sigma_{\text{pico}-i, t}\), is in the range of [0,1]. We also define \(N_{\text{macro-cor-i, t}}\), \(N_{\text{macro-nei-i, t}}\), and \(N_{\text{macro-capacity}}\) to represent the number of UEs being served by a corresponding macro eNB of the \(i\)th pico eNB at time \(t\), the number of UEs being served by a neighboring macro eNB of the \(i\)th pico eNB at time \(t\), and the total number of UEs that can be served by a macro eNB, respectively. Note that the corresponding macro eNB of the \(i\)th pico eNB and the neighboring macro eNB of the \(i\)th pico eNB are illustrated in Fig. 3.

The proportional-fair (PF) of the \(i\)th macro eNB, \(PF^{\text{macro}-i}(t)\), and the PF of the pico eNBs which are in the coverage area of the \(i\)th macro eNB, \(PF^{\text{pico}-i}(t)\), are defined in Eqs. (4) and (5), respectively \[13\]:

\[
PF^{\text{macro}-i}(t) = \frac{1}{N_{\text{macro-total-}\text{, }i}(t)} \sum_{u=1}^{N_{\text{macro-total-}\text{, }i}(t)} \sum_{k=1}^{n_{\text{macro-PRB}}} \frac{r_{\text{macro-i, u, k}}(t)}{R_{\text{macro-i, u}}(t)}
\]

where

\(N_{\text{macro-total-}\text{, }i}(t)\) is the total number of active UEs that connect to the \(i\)th macro eNB in the \(i\)th ABS period.

\(r_{\text{macro-i, u, k}}(t)\) is the estimated throughput of UE \(u\), which connects to the \(i\)th macro eNB, at the \(k\)th physical resource block (PRB) in the \(i\)th ABS period. The estimated throughput is based on the channel quality indication (CQI) reported by UE \(u\).

\(R_{\text{macro-i, u}}(t)\) is the estimated long term throughput of UE \(u\), which connects to the \(i\)th macro eNB, in the \(i\)th ABS period.

\(n_{\text{macro-PRB}}\) is the total number of PRBs used by UE \(u\), which connects to the \(i\)th macro eNB.
\[ \text{PF}_{\text{pico-i}}(t) = \frac{1}{N_{\text{pico-total-i}}(t)} \sum_{t'=1}^{\text{ABS}} \sum_{k=1}^{n_{\text{pico-i-PRB}}(t)} \frac{r_{\text{pico-i-u}}(t)}{R_{\text{pico-i-u}}(t)} \]  

\( N_{\text{pico-total-i}}(t) \) is the total number of active UEs, which connect to pico eNBs, that are located in the coverage area of the \( i \)-th macro eNB in the \( t \)-th ABS period.

\( r_{\text{pico-i-u}}(t) \) is the estimated throughput of UE \( u \), which connects to pico eNBs that are located in the coverage area of the \( i \)-th macro eNB, at the \( k \)-th PRB in the \( t \)-th ABS period. The estimated throughput is based on the CQI reported by UE \( u \).

\( R_{\text{pico-i-u}}(t) \) is the estimated long term throughput of UE \( u \), which connects to pico eNBs that are located in the coverage area of the \( i \)-th macro eNB, in the \( t \)-th ABS period.

\( n_{\text{pico-i-PRB}} \) is the total number of PRBs used by UE \( u \), which connects to pico eNBs that are located in the coverage area of the \( i \)-th macro eNB.

### 4. PROPOSED SON-BASED CELL SIZE ADAPTION (SCSA) AND TRAFFIC ADAPTIVE ENHANCED INTER-CELL INTERFERENCE COORDINATION (TAEICIC)

The proposed SCSA uses dynamic multi-threshold load management to dynamically set the transmission power of each pico eNB by adjusting the pilot power so as to achieve load balancing between macro and pico cells and mitigate the inter-cell interference problem. In addition, the proposed TAEICIC utilizes a scheduling metric, PF, which is the estimated throughput based on the CQI reported by a UE divided by the estimated long term average throughput achieved by the UE, to dynamically allocate an appropriate number of ABSs in each ABS period in a macrocell so as to mitigate the interference from the macrocell to its adjacent picocells. In the proposed SCSA, we define three dynamically changed loading thresholds (upper threshold \( T_U \), middle threshold \( T_M \), and lower threshold \( T_L \)) for each pico eNB. The adjustment of loading thresholds is to reflect the loadings of the corresponding macro eNB, the neighboring macro eNB, and the pico eNB for load balancing among macro and pico eNBs.

#### 4.1 Proposed SON-based Cell Size Adaption (SCSA)

The proposed SCSA algorithm is composed of a transmission power adaption algorithm (Algorithm 1) and a multi-threshold updating algorithm (Algorithm 2). Algorithm 1 is triggered when \( \sigma_{\text{pico-i-u}} > T_U \) or \( \sigma_{\text{pico-i-u}} < T_L \). In Algorithm 1, if \( \sigma_{\text{pico-i-u}} > T_U \), the \( i \)-th pico eNB needs to reduce its transmission power so as to offload some UEs to its corresponding macro eNB and the neighboring macro eNB, and if \( \sigma_{\text{pico-i-u}} < T_L \), the \( i \)-th pico eNB needs to increase its transmission power so as to reduce the loadings of its corresponding macro eNB and the neighboring macro eNB. Algorithm 1 aims to adjust the loading of the \( i \)-th pico eNB to \( T_0 \) so as to avoid that Algorithm 1 is triggered too often owing to overloading or underloading. Therefore, the transmission power of the \( i \)-th pico eNB is set to the maximum pilot power of the \( i \)-th pico eNB \( \times T_M \). Note that a pico eNB strengthens its transmission power to increase its loading by serving more UEs and decreases its transmission power to reduce its loading by serving fewer UEs.
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Algorithm 1: Transmission power adjusted for the $i$th pico eNB

**Input:** $N_{\text{pico-i}}, N_{\text{pico-capacity}}$

**Output:** Transmission power of the $i$th pico eNB

1. if $\sigma_{\text{pico-i}, t} > T_U$ $\parallel \sigma_{\text{pico-i}, t} < T_L$
2. $\sigma_{\text{pico-i}, t} = T_M$
   // The $i$th pico eNB adjusts its transmission power by setting its pilot power to the maximum pilot power of the $i$th pico eNB
3. end if

Algorithm 2: Multi-threshold updating for the $i$th pico eNB

**Input:** $N_{\text{macro-cor-i}}, N_{\text{macro-nei-i}}, N_{\text{pico-i}}, N_{\text{macro-capacity}}, N_{\text{pico-capacity}}$

**Output:** $T_U, T_M, T_L$

1. if the $i$th pico eNB received updated $N_{\text{macro-cor-i}}$ or $N_{\text{macro-nei-i}}$
2. $L_{\text{avg}} = \frac{\sigma_{\text{pico-i}, t} + \beta \times \sigma_{\text{macro-cor-i}, t} + (1 - \beta) \times \sigma_{\text{macro-nei-i}, t}}{3}$
3. $\mu = \frac{\beta \times N_{\text{macro-cor-i}, t} + (1 - \beta) \times N_{\text{macro-nei-i}, t}}{N_{\text{pico-i}, t} + N_{\text{macro-cor-i}, t} + N_{\text{macro-nei-i}, t}}$
4. $T_U = L_{\text{avg}} + L_{\text{avg}} \times \mu$

In Algorithm 2, we base on $N_{\text{macro-cor-i}}, N_{\text{macro-nei-i}},$ and $N_{\text{pico-i}}$ to dynamically adjust the $T_U, T_M,$ and $T_L$ of the $i$th pico eNB. The idea of determining $T_U$ is that if the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are higher (lower), the higher (lower) $T_U$ of the $i$th pico eNB is set. The reasons why we set $T_U$ in this way are described as follows. If the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are heavy, the $i$th pico eNB will increase its $T_U$ so as to avoid offloading its loading to the two heavy loaded macro eNBs. On the contrary, if the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are light, the $i$th pico eNB will decrease its $T_U$ so as to offload its load to the two light loaded macro eNBs. The idea of determining $T_L$ is that if the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are higher (lower), the higher (lower) $T_L$ of the $i$th pico eNB is set. The reasons why we set $T_L$ in this way are described as follows. If the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are heavy, the $i$th pico eNB will increase its $T_L$ so as to share the two heavy loaded macro eNBs’ loads. On the contrary, if the loadings of the corresponding macro eNB and the neighboring macro eNB of the $i$th pico eNB are light, the $i$th pico eNB needs to decrease its $T_L$ so as to avoid unnecessary handovers from UEs served by the two light loaded macro eNBs. In this way, each pico eNB can effectively adjust its transmission power to reflect its corresponding and neighboring macro eNBs’ loadings. In addition, $T_M$ is the average of $T_U$ and $T_L$. Note that the parameters used in Algorithm 2 will be updated in the beginning of each ABS period through the X2 interface. Remind that since the $i$th pico eNB and its corresponding macro eNB are in the same cell, $\beta$ in Algorithm 2 is a weighting factor that is used to pay more attention to the loading of the corresponding macro eNB than that of the neighboring macro eNB.
5. \( T_L = L_{\text{avg}} - L_{\text{avg}} \times (1 - \mu) \)

6. \( T' = \frac{T_x + T_y}{2} \)

7. end if

4.2 Proposed Traffic Adaptive Enhanced Inter-cell Interference Coordination (TAeICIC)

In the proposed TAeICIC, we use the ratio of the loading of a pico eNB which has the highest loading among the pico eNBs located within the same corresponding (the \(i\)th) macro eNB over the total loading of all the pico eNBs located within the same corresponding (the \(i\)th) macro eNB plus the loading of the corresponding macro eNB as the corresponding (the \(i\)th) macro eNB’s muting ratio \(\mu_i\) in the first ABS period \(T_{ABS}\), as shown in Eq. (6):

\[
\mu_i = \max \left( \frac{N_{\text{pico-i},1} + N_{\text{pico-i},2} + N_{\text{pico-i},3}}{N_{\text{macro-i},1} + \sum_{j \neq i} N_{\text{pico-j},1}} \right)
\]  

(6)

In other words, muting ratio \(\mu_i\) is the ratio of ABSs allocated in an ABS period for the \(i\)th macro eNB. In this way, each macro eNB can allocate ABSs for its pico eNBs according to the loading of the pico eNB with the highest load. Then, the \(i\)th macro eNB uses Algorithm 3 to adjust muting ratio \(\mu_i\) at the beginning of each ABS period. Therefore, Algorithm 3 can be used to obtain the number of ABSs allocated in each \(T_{ABS}\). In Algorithm 3, a higher muting ratio will be obtained if the \(i\)th pico eNB’s performance decreases (PF\(_{p-i}\) increases) and at the same time their corresponding macro eNB’s (the \(i\)th macro eNB) performance increases (PF\(_{m-i}\) decreases). Otherwise, if the \(i\)th macro eNB’s performance decreases (PF\(_{m-i}\) increases), a lower muting ratio will be obtained. Note that in Algorithm 3, the number of ABSs allocated in each ABS period depends on the growth rates of PF\(_{m-i}\) and PF\(_{p-i}\), as detailed in Algorithm 3. In contrast, the PF-ABS proposed in [13] only increases or decreases one ABS in each ABS period while the proposed TAeICIC increases or decreases a different number of ABSs according to the growth rates of PF\(_{m-i}\) and PF\(_{p-i}\). In this way, the proposed TAeICIC can allocate a more appropriate number of ABSs than the PF-ABS. Therefore, the proposed TAeICIC has better performance than the PF-ABS.

Algorithm 3: ABS allocation for the \(i\)th macro eNB

Input: PF\(_{m-i}\)(\(t\)), PF\(_{m-i}\)(\(t-1\)), PF\(_{p-i}\)(\(t\)), PF\(_{p-i}\)(\(t-1\))

Output: \(\mu\)

1. if (PF\(_{m-i}\)(\(t\)) > PF\(_{p-i}\)(\(t-1\))) and (PF\(_{m-i}\)(\(t\)) < PF\(_{m-i}\)(\(t-1\)))

2. \(\mu = \mu + \left[ \frac{PF_{m-i}(t)}{PF_{m-i}(t-1)} \right] \times \frac{1}{T_{ABS}} \left( 1 - \frac{1}{T_{ABS}} \right) \)

3. \(\mu = \mu + \left[ \frac{PF_{p-i}(t)}{PF_{p-i}(t-1)} \right] \times \frac{1}{T_{ABS}} \)

4. else
5. ANALYTIC MODEL

The cellular concept does not apply broadcasting over large areas. Smaller areas, called cells, instead are handled by less powerful eNBs that use less power for transmission. The available spectrum can then be re-used from one cell to another to increase the capacity of the system [15]. To support more UEs in urban areas, the heterogeneous cellular architecture has been proposed. The LTE-A heterogeneous network (HetNet), which is a heterogeneous cellular architecture that can increase the capacity of LTE-A, is composed of high power macrocells and low power picocells. In this section, we analyze the performance of the proposed SCSA+TAeICIC, which focuses on achieving load balancing among macrocells and picocells and mitigating the interference from macrocells to picocells so as to reduce the radio interface delay experienced by each UE. Two performance metrics related to the radio interface delay, the packet error rate (PER) and the expectation of the packet retransmission count (PRC), for UEs are analyzed. In order to analyze the proposed SCSA+TAeICIC, we model the packet transmission over the wireless channel between UE and eNB by the $M/mixEk/1$ queuing model [16] and assume the packet transmission of a UE is either in success state (SS) or failure state (FS). The SS state represents that the packet transmission from a UE to an eNB is successful, and the FS state represents that the packet transmission from a UE to an eNB is failed. Fig. 4 shows the state transition diagram of the Markov process for packet transmission. We assume that the arrivals of failed packet transmissions are a Poisson process with arrival rate $\lambda$, and the departure rate of the FS state is $\theta$. The inter-arrival time of two consecutive failed packet transmissions is exponentially distributed with the probability density function (PDF), as shown in Eq. (7) [17-19].
\[ f(t) = \lambda e^{-\lambda t} \quad t \geq 0 \] (7)

Let \( \delta \) denote a random variable that represents the duration of a failed packet transmission. Assume that \( \delta \) has the mixed Erlang distribution with the PDF

\[ f_{\delta}(t) = \sum_{i=1}^{I} c_i \left( \phi_i t^i \right) (r_i - 1)! \phi_i e^{-\phi_i t} \]

where \( \sum_{i=1}^{I} c_i = 1. \) (8)

Note that in Eq. (8), \( I, c_i, r_i \) and \( \phi_i \) determine the shape and scale of the distribution \([18]\). We selected the mixed Erlang distribution because it has been proven that it can well approximate many other distributions \([17-19]\). Thus, the expectation of \( \delta \) is expressed as

\[ E(\delta) = \int_{t=0}^{\infty} f_{\delta}(t) t \, dt \]
\[ = \sum_{i=1}^{I} c_i \phi_i^i \int_{t=0}^{\infty} t^i e^{-\phi_i t} \, dt. \] (9)

By Laplace transform, we get

\[ E(\delta) = \sum_{i=1}^{I} c_i \left( \frac{r_i}{\phi_i} \right). \] (10)

Fig. 4. State transition diagram of the Markov process for packet transmission.

Then, the departure rate, \( \theta \), can be expressed as \( \theta = 1/E(\delta) \). Furthermore, let the state probabilities of SS and FS be \( \pi_0 \) and \( \pi_1 \), respectively. From the Birth-Death process of queueing theory, we get

\[ \pi_0 = (1 + \lambda / \theta)^{-1} \] (11)

and

\[ \pi_1 = (\lambda \theta (1 + \lambda / \theta)^{-1}. \] (12)

The packet error rate (PER) is expressed as

\[ PER = \pi_1 \int_{t=0}^{\infty} f(t) \, dt + \pi_1 \]
\[ = \pi_1 (-e^{-\lambda t} \mid_{t=\infty} + \pi_1 \]
\[ = 1 - \pi_0 e^{-\lambda t}. \] (13)
where $t_p$ is the average radio interface delay experienced by a UE.

Let $\sigma$ denote the packet retransmission count for a UE successfully transmitting a packet to an eNB. Therefore, the expectation of $\sigma$ is expressed as follows:

$$E(\sigma) = \sum_{n=1}^{\infty} n \left( 1 - \pi_0 e^{-\lambda t} \right)^{n-1} \left( \pi_0 e^{-\lambda t} \right) - 1. \quad (14)$$

Note that in the first part of Eq. (14), $\sum_{n=1}^{\infty} n \left( 1 - \pi_0 e^{-\lambda t} \right)^{n-1} \left( \pi_0 e^{-\lambda t} \right)$ represents the expectation of 1 (the first packet transmission) plus the packet retransmission count. Thus, Eq. (14) represents the expectation of the packet retransmission count for a UE successfully transmitting a packet to an eNB.

### Table 2. Parameters setting for performance evaluation [12, 20, 13].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro eNB – macro eNB distance</td>
<td>1.732 km</td>
</tr>
<tr>
<td>Macro eNB – pico eNB distance</td>
<td>0.7 km</td>
</tr>
<tr>
<td>Path loss</td>
<td>$137.09 + 35.22 \times \log(d[\text{km}])$</td>
</tr>
<tr>
<td>Shadowing std</td>
<td>4 dB</td>
</tr>
<tr>
<td>Macro eNB power</td>
<td>(Pilot power) 20 dB (Tx) 46 dBm</td>
</tr>
<tr>
<td>Pico eNB power</td>
<td>(Pilot power) 0–20 dB (Tx) 37 dBm</td>
</tr>
<tr>
<td>Uplink data rate</td>
<td>500 Mbps</td>
</tr>
<tr>
<td>Downlink data rate</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>$\beta$ weighting factor in Algorithm 2</td>
<td>2/3</td>
</tr>
<tr>
<td>ABS period ($T_{ABS}$)</td>
<td>8 subframes [13]</td>
</tr>
<tr>
<td>$N_{macro-capacity}$</td>
<td>300 UEs</td>
</tr>
<tr>
<td>$N_{pico-capacity}$</td>
<td>150 UEs</td>
</tr>
<tr>
<td>Cells layout</td>
<td>See Fig. 3</td>
</tr>
<tr>
<td>Packet size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>$\delta$ is a mixed Eralng-2 random variable</td>
<td>$c_1 = c_2 = 0.5$ \ \ $\phi_1 = 2$, $\phi_2 = 3$ (/ms)</td>
</tr>
</tbody>
</table>

### 6. PERFORMANCE EVALUATION

In this section, we first describe simulation and analytic setup, and evaluation metrics. Then, we compare the proposed SCSA+TAeICIC with DI [7], PF-ABS [13], and IL-ABS [13] in terms of average throughput of eNBs, average throughput of UEs, average radio interface delay of UEs, and average energy consumption per pico eNB. In addition, based on the analytic model derived in the last section, we also compare analytic results and simulation results of the proposed SCSA+TAeICIC with DI [7], PF-ABS [13], and IL-ABS [13] in terms of PER and PRC. A simulation model using NS-2 was developed to validate the analytic model. The simulation model is based on the analytic model de-
son-based cell size adaptation and traffic adaptive eICIC

scribed in Section 5. The same parameter settings shown in Table 2 were used for simulation as well as for analysis. Simulation results were obtained by the average of 10,000 runs.

6.1 Simulation and Analytic Setup, and Evaluation Metrics

We simulated an LTE-A heterogeneous network, which has 7 macro eNBs and 3 pico eNB within each macro eNB, as shown in Fig. 3. There are 750 UEs in each macro-cell, and all UEs are distributed uniformly and randomly. The percentage of active UEs is between 0.7 and 1 [12]. Table 2 shows the simulation setup. First, we define the average throughput of UEs as the throughput averaged over all active UEs, the average throughput of eNBs as the throughput averaged over all macro and pico cells, the average radio interface delay of UEs as the radio interface delay averaged over all active UEs, and the average energy consumption per pico eNB as the energy consumption averaged over all pico eNBs. In addition, for the analytic setup, without loss of generality, we assume \( \delta \) is a mixed Erlang-2 random variable and the coefficients for \( \delta \) are set to \( c_1 = c_2 = 0.5 \) [18, 19].

6.2 Simulation Results

In this section, we compare the proposed SCSA+TAeICIC with DI [7], PF-ABS [13], and IL-ABS [13]. Figs. 5 and 6 show the average throughput of eNBs and the average throughput of UEs, respectively. We observed that the throughput degrades as the number of UEs increases. This is because collisions may occur as the number of UEs increases and the number of UEs granted to uplink/downlink access decreases. Fig. 5 demonstrates that the proposed SCSA+TAeICIC’s average throughput of eNBs is 15.43% higher than DI’s, 25.66% higher than PF-ABS’s, and 31.49% higher than IL-ABS’s. Fig. 5 also shows that the proposed TAeICIC’s average throughput of eNBs is higher than PF-ABS’s as well as IL-ABS’s. Fig. 6 shows that the proposed SCSA+TAeICIC’s average throughput of UEs is 16.25% higher than DI’s, 29.39% higher than PF-ABS’s, and 39.38% higher than IL-ABS’s. Fig. 6 also demonstrates that the proposed TAeICIC’s average throughput of eNBs is higher than PF-ABS’s as well as IL-ABS’s. Fig. 7 shows the average radio interface delay of UEs. The radio interface delay increases as the number of UEs increases. The reason is that when the number of UEs increases, collisions may increase. This results in the increase of radio interface delay. Fig. 7 demonstrates that the proposed SCSA+TAeICIC’s average radio interface delay of UEs is 81.01% lower than DI’s, 84.97% lower than PF-ABS’s, and 86.52% lower than IL-ABS’s. Fig. 7 also shows that the proposed TAeICIC’s average radio interface delay of UEs is lower than PF-ABS’s as well as IL-ABS’s. Fig. 8 shows that the proposed SCSA’s average energy consumption per pico eNB is 54.83% lower than each of the three related methods. This is because the proposed SCSA can adaptively adjust the transmission power of each pico eNB according to its utilization while the related methods use fixed transmission power. In addition, the load balance metric (LBM) [21], ranging from 1 to the number of eNB, of the proposed SCSA is 1.1, which is very close to 1. Note that small values of the LBM indicate better load balancing performance than large values [21]. This proves that the proposed SCSA indeed achieves load balancing.
Fig. 5. Average throughput of eNBs.

Fig. 6. Average throughput of UEs.

Fig. 7. Average radio interface delay of UEs.
6.3 Analytic Results

By Eq. (13), Figs. 9-11 demonstrate that the PER of the proposed SCSA+TAeICIC is 15.61% lower than that of the DI, and 23.51% lower than that of the PF-ABS, and 25.38% lower than that of the IL-ABS, respectively. Figs. 12 and 13 demonstrate that the PER of the proposed TAeICIC is lower than that of the PF-ABS as well as that of the IL-ABS. As shown in Figs. 9-13, analytic and simulation results are very close, which confirms the validity of our analytic model.

By Eq. (14), Figs. 14-16 demonstrate that the PRC of the proposed SCSA+TAeICIC is 13.79% lower than that of the DI, and 23.13% lower than that of the PF-ABS, and 32.63% lower than that of the IL-ABS, respectively. Fig. 17 and 18 demonstrate that the PRC of the proposed TAeICIC is lower than that of the PF-ABS as well as that of the IL-ABS. As shown in Figs. 14-18, analytic and simulation results are very close, which confirms the validity of our analytic model.
Fig. 10. PER comparison between the proposed SCSA+TAeICIC and PF-ABS.

Fig. 11. PER comparison between the proposed SCSA+TAeICIC and IL-ABS.

Fig. 12. PER comparison between the proposed TAeICIC and PF-ABS.
Fig. 13. PER comparison between the proposed TAeICIC and IL-ABS.

Fig. 14. PRC comparison between the proposed SCSA+TAeICIC and DI.

Fig. 15. PRC comparison between the proposed SCSA+TAeICIC and PF-ABS.
Fig. 16. PRC comparison between the proposed SCSA+TAeICIC and IL-ABS.

Fig. 17. PRC comparison between the proposed TAeICIC and PF-ABS.

Fig. 18. PRC comparison between the proposed TAeICIC and IL-ABS.
In summary, the improvements of the proposed SCSA+TAeICIC in terms of PER and PRC explain why the proposed SCSA+TAeICIC is better than DI, PF-ABS, and IL-ABS in terms of average throughputs of eNBs and UEs, and average radio interface delay of UEs.

6.4 Implementation Issues of the SON in LTE-A HetNets

In this section, we will describe how the proposed SON mechanisms, SCSA+TAeICIC, can be implemented in LTE-A HetNets. In 3GPP specifications [22, 23], the X2 interface can be used to exchange overload and traffic load information, such as utilization of an eNB for the proposed SCSA and proportional fair of an eNB for the proposed TAeICIC, between eNBs in LTE-A HetNets. In summary, the eNBs can control the traffic load appropriately. In addition, in a 3GPP SON related specification [11], the SON load balancing algorithm can be implemented in an eNB to optimize the coverage of each eNB. Therefore, the proposed SCSA can be implemented in an eNB of LTE-A SON HetNets.

7. CONCLUSION

In this paper, we have presented the SON-based Cell Size Adaption (SCSA) and Traffic Adaptive enhanced Inter-cell Interference Coordination (TAeICIC) schemes to enhance spectrum efficiency in LTE-A HetNets. The proposed SCSA uses dynamic multi-threshold load management to dynamically adjust the transmission power of each pico eNB. In addition, the proposed TAeICIC utilizes the proportional-fair (PF) to dynamically allocate an appropriate number of ABSs in an ABS period in a macrocell so as to mitigate the interference from the macrocell to its adjacent picocells. Simulation results have shown that the proposed SCSA+TAeICIC’s average throughput of eNBs is 15.43% higher than DI’s, 25.66% higher than PF-ABS’s, and 31.49% higher than IL-ABS’s. Its average throughput of UEs is 16.25% higher than DI’s, 29.39% higher than PF-ABS’s, and 39.38% higher than IL-ABS’s. Its average radio interface delay of UEs is 81.01% lower than DI’s, 84.97% lower than PF-ABS’s, and 86.52% lower than IL-ABS’s. The proposed SCSA’s average energy consumption per pico eNB is 54.38% lower than all the above three related methods. Therefore, the significance of the proposed SCSA+TAeICIC is that it can enhance the Quality of Experience (QoE) of mobile users and reduce the OPEX of the operators in LTE-A HetNets.

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