Management of Neighbor Cell Lists and Physical Cell Identifiers in Self-Organizing Heterogeneous Networks

Jaechan Lim and Daehyoung Hong

Abstract: **In this paper, we propose self-organizing schemes for the initial configuration of the neighbor cell list (NCL), maintenance of the NCL, and physical cell identifier (PCI) allocation in heterogeneous networks such as long term evolution systems where lower transmission power nodes are additionally deployed in macrocell networks. Accurate NCL maintenance is required for efficient PCI allocation and for avoiding handover delay and redundantly increased system overhead. Proposed self-organizing schemes for the initial NCL configuration and PCI allocation are based on evolved universal terrestrial radio access network NodeB (eNB) scanning that measures reference signal to interference and noise ratio and reference symbol received power, respectively, transmitted from adjacent eNBs. On the other hand, the maintenance of the NCL is managed by adding or removing cells based on periodic user equipment measurements. We provide performance analysis of the proposed schemes under various scenarios in the respects of NCL detection probability, NCL false alarm rate, handover delay area ratio, PCI conflict ratio, etc.**

Index Terms: **Evolved universal terrestrial radio access network (E-UTRAN), heterogeneous networks (HetNets), long term evolution (LTE), neighbor cell list (NCL), physical cell identifier (PCI), self-organizing networks (SON).**

I. INTRODUCTION

Heterogeneous networks (HetNets) such as long term evolution (LTE) (or, more precisely, LTE-advanced) systems aim at enhanced system performance in many respects. In particular, enhancement of coverage and capacity performance can be achieved in the way of deploying low power nodes such as pico and femto cells in a macro-cell layout. Frequent installations and removals of low-power nodes as occasion demands may require self-organizing HetNets by which simplified system installation procedure, maintenance, and autonomous adaptation to varying network environment are easily achievable [1], [2]. Particularly, physical cell identifier (PCI) allocation, neighbor cell configuration and management, and, optimized handover parameter setting are of interest for current research topics in self-organizing networks [2], [3]. Each evolved universal terrestrial radio access network (E-UTRAN) NodeB (eNB) possesses a neighbor cell list (NCL) that includes physical cell identifiers (PCIs) of the neighbor cells; and the PCI is essential information for handover. The accuracy of an NCL affects handover performance significantly since handover to a cell that is not on the NCL will cause handover delay. On the other hand, the maintenance of falsely detected cell information on the NCL results in redundantly increased system overhead. Therefore, an accurate initial NCL configuration and maintenance are desirable.

We propose an eNB scanning scheme for self-configuration of the initial NCL in the pre-operational state when user equipments (UEs) have not yet been registered or activated in networks. In this scheme, neighbor cells can be identified based on the measured reference signal to interference and noise ratio (SINR) transmitted from adjacent eNBs depending on whther it is greater than a predetermined threshold or not. The threshold needs to be determined in such a way that only true neighbor cells are included in NCL as much as possible. A number of self-initial-configuring schemes of the NCL have been proposed based on the local-geographic information, antenna pattern, transmission power, etc., which are mainly acquired by an upper-level node and accordingly, do not reflect the true radio environment of networks [4]–[6]. We show that the proposed eNB scanning scheme outperforms, particularly in HetNet scenarios, the traditional distance based scheme in this initial NCL configuration.

The maintenance of an NCL is managed by updating the list elements based on UE measurement rather than eNB scanning; therefore, the true radio environment is reflected in this case. A scheme for eliminating non-neighbor cells from the list adopting the "time-to-leave (TTL)" parameter was proposed in [7] based on periodic UE measurement. The performance of this NCL updating based on UE measurement is affected by the number of UEs and the types of HetNets.

The NCL also includes the PCIs of neighbor cells. We propose a self-organizing scheme for PCI allocation to newly installed eNBs based on eNB scanning. The efficient allocation of limited PCI resources with a low PCI conflict ratio (which means an identical PCI is allocated to neighboring cells) is targeted in this study. By selecting the proper value for a defined parameter in the scheme, we can make the proposed scheme outperform the random allocation scheme that is specified in the LTE technical specification [1].

The rest of this paper is organized as follows. In Section II, we describe the initial NCL configuration scheme based on eNB scanning. In Section III, the maintenance scheme of the NCL based on UE measurement is discussed. A PCI allocation scheme in self-organizing HetNets is proposed in Section IV, and simulations to verify the validity of the proposed schemes follow. Finally, concluding remarks are presented.

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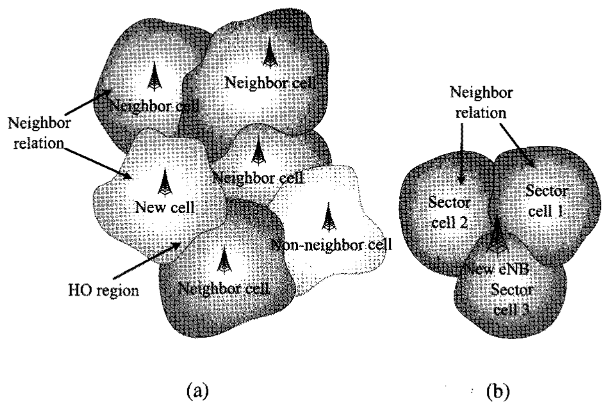


Fig. 1. (a) Neighbor cell condition and (b) neighbor relation of three sector cells.

II. INITIAL NCL CONFIGURATION

A. Ideal NCL

The basic condition for a neighbor relation between two cells is coverage overlap with each other, and this overlap area forms an HO region. The neighbor relations between cells are portrayed in Fig. 1. In sectorized cell environment, sector cells belonging to the same eNB are in the neighbor relation as shown in Fig. 1(b). The ideal NCL consists of the cells that satisfy the neighbor cell condition described above. In the self-configuration of the initial NCL, it is desirable to acquire an NCL that matches the ideal NCL as much as possible based on eNB scanning. A user will experience delay when handover is attempted into a neighbor cell that is not included in the NCL. On the other hand, if the NCL includes any cells that are not in the neighbor relation, system overhead is wasted due to unnecessary management and maintenance. Therefore, an accurate NCL configuration is desired to prevent handover delay and to save system overhead.

B. eNB Scanning

The method of eNB scanning by which an eNB autonomously measures and decodes the broadcasted signals from adjacent cells is similar to the UE measurement process [2]. In the pre-operational state of networks, a newly deployed eNB is powered up and has the backbone connection (e.g., elements of an evolved packet core such as a mobility management entity, serving gateway, and packet data network gateway), but it does not start services to any UEs. Accordingly, the newly deployed eNB cannot receive the measurement report from UEs at this stage. The UE measurement report includes adjacent cell information which is measured at various locations of whole coverage area. In particular, if it is from the handover region, accurate NCL configuration is attainable. It is challenging to acquire the information about true radio environment and network topology since only limited information from the operating and management (O&M) system is supplied during the pre-operational state. Further, the tasks related to handover are managed mainly by eNBs directly in the LTE technology. Therefore, we use the method of eNB scanning to detect neighbor cells, and it can effectively reflect the real radio environment and reduce system overhead. However, eNB scanning has a defect: Since eNB scanning is performed at the center of cells, it is impossible to reflect the cell boundary environment exactly. The signal transmitted from a neighbor cell tends to degenerate while propagating from the cell boundary to the center. Therefore, it is not tractable to determine the "neighbor cell decision threshold" exactly based on eNB scanning. We make several assumptions in the application of eNB scanning: (1) The eNB receiver has superior sensitivity to UE has, so it can decode weak signals (e.g., below -6dB); (2) the measured information obtained by eNB scanning contains the PCI and reference SINR of adjacent cells; and the cell types (e.g., macro, pico, femto, etc.) can be classified from the PCI.

C. The Scheme

C.1 Procedure

a) Collect the information (PCI, SINR, etc.) of adjacent cells based on eNB scanning.
b) Determine the neighbor cell i of which the measured SINR is higher than the SINR threshold among the detected cells.

$$\mathrm{SINR}^{i}_{\mathrm{eNBscan}} \geq \mathrm{Threshold}_{\mathrm{neighbor}} \tag{1}$$

c) Configure the initial NCL containing the selected cells as the neighbor cells.
d) Connect the so called X2 interface between the newly deployed eNB and the eNBs of the neighbor cells for direct communications.

After the initial NCL self-configuration procedure is completed by the newly deployed eNB, a further process should follow by the eNBs of the neighbor cells, which also notice in the change of network topology and add a new neighbor cell to their NCLs. In traditional systems, networks demand a manual update of a neighbor cell by operators. On the other hand, in LTE technology, a newly deployed eNB sends its identification information via direct X2 interface to its neighbor cells. Through this manner, neighbor cells update their NCLs.

C.2 System Performance According to SINR Threshold

The SINR threshold plays a key role in the proposed algorithm. If an excessively high threshold is selected, it is possible that several handover candidate cells might be missed from the NCL because, even if the received signal strength is high enough for handover at the cell boundary, the measured SINR value at the location of the new eNB can be below the threshold. Nonetheless, there is a merit in reducing system overhead because many non-neighbor cells are excluded. On the contrary, if the selected SINR threshold is too low, most of potential handover candidate cells are contained in the initial NCL. In this case, the handover delay problem is avoided. However, a large number of non-neighbor cells may also be added to the NCL. Therefore, the system overhead is increased. Fig. 2 illustrates the range of neighbor cells depending on different SINR thresholds.

D. SINR Threshold Depending on Cell

As mentioned in the introduction section, LTE systems provide several cell types depending on the levels of the transmis-

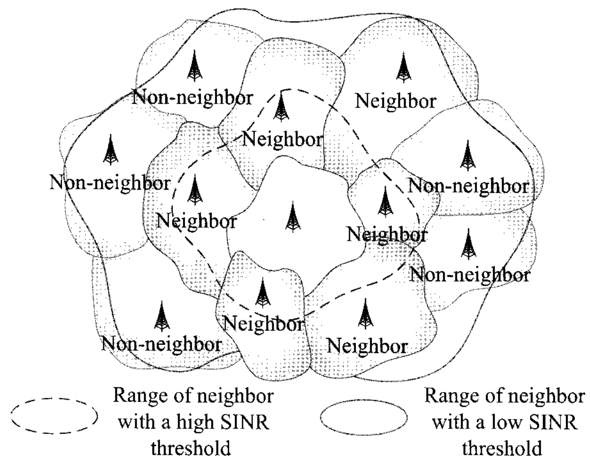


Fig. 2. Range of neighbor cells according to SINR threshold.

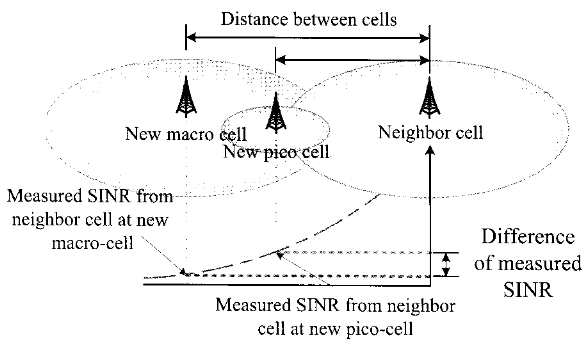


Fig. 3. Comparison of received SINR strength according to the new cell type.

sion power of the eNBs. In this section, we explain the reason why we have to determine the SINR threshold depending on the cell types of a newly deployed cell and adjacent cells in HetNets.

At first, we consider the effect of the cell type of a newly deployed eNB. If a new eNB is the macro-type, the coverage size formed by the new eNB is larger than that of the pico-type, and the maximum distance between the new eNB and any neighbor cells will be increased. In this case, the SINR threshold should be determined to be relatively low. If the new eNB is the pico-type, since a pico cell has small coverage size[1], only cells located closely to the new eNB can be neighbor cells. In this case, the SINR threshold should be selected to be relatively higher than that of a macrocell. The effect of the cell type of the new eNB on the SINR threshold is illustrated in Fig 3.

Next, we investigate the effect of the cell types of adjacent cells on determining the SINR threshold. Since a macro cell is designed for providing wireless service with large coverage size, the transmission power is set higher than that of a picocell, and signal attenuation is not as severe with distance as compared

[1] In this paper, we do not consider the range expansion of a pico-cell by which the coverage of a pico-cell is intentionally expanded for various purposes. The range expansion of pico cells can be obtained by cell association of UEs based on the *minimum path-loss*, *offset (biased)* reference signal received power (RSRP), or *hotzone first* method rather than the maximum RSRP only [8], [9]. We assume that the coverage size of pico-cells can be controlled uniformly by adjusting the tx-power of picocells based on the self-organizing networks (SON) scheme no matter where picocells are located in a macrocell.

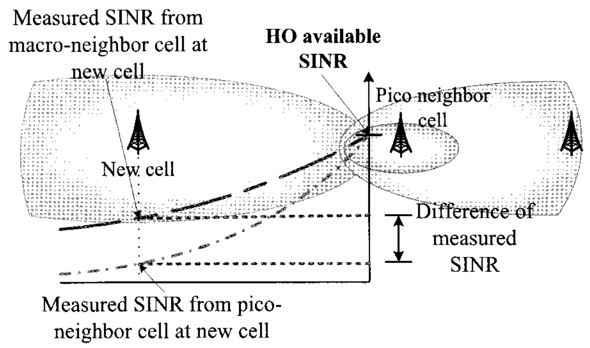


Fig. 4. Comparison of received SINR according to the neighbor cell type.

to the case of a pico-cell. On the other hand, a pico cell has low transmission power and severe signal attenuation: This is because the path-loss characteristic is different due to the antenna height, etc. Therefore, even if the SINR measured at the cell-boundary of a newly deployed eNB is similar regardless of types, the strength measured at the eNB (center of the cell) of the new cell will differ depending on the cell types as shown in Fig. 4. Consequently, the measured SINR values of adjacent macro eNBs are generally higher than that of an adjacent pico eNB. For this reason, the SINR threshold should be set higher when adjacent cells are known to be the macro type. On the other hand, if adjacent cells are known to be the pico type, the SINR threshold should be set lower than that of the macro type.

III. MAINTENANCE OF NCL

The maintenance of the NCL is managed by adding up or removing a cell (eNB) on the list in a self-organizing manner. As opposed to the case of initial NCL configuration, the maintenance of the NCL is managed based on UE measurement rather than eNB scanning.

A. Adding an Element on the NCL

Based on UE measurement, a serving eNB detects a newly deployed eNB and receives its information, e.g., the PCI and SINR. Then, the new neighbor cell is added if it is not on the list already. The detailed procedure is described in Fig. 5, as specified in the technical specification [1]. Because this process relies on UE measurement, the number of UEs in the serving cell may affect the performance. For instance, this self-organizing scheme may show degraded performance in metropolitan areas during the late night due to the reduced number of users. The performance of this scheme is also affected by the cell types (e.g., macro, pico, and femto) since the large size of the handover region may result in more active UE measurement than that in the case of a small overlapping coverage area. Therefore, higher performance is expected when macrocells are involved than in the case where picocells are involved.

B. Eliminating an Element from NCL

In the eliminating scheme, a cell is removed from an NCL if the UE measurement report about the cell is not delivered during

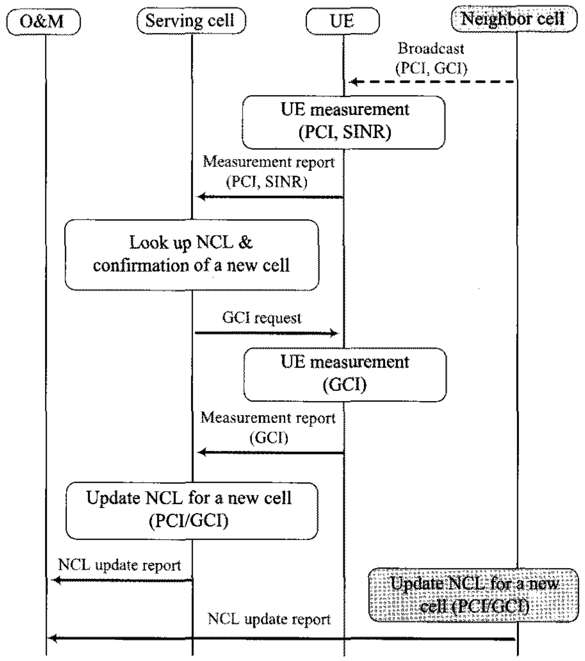


Fig. 5. Process of adding a new neighbor cell based on UE measurement.

a certain time period, i.e., the TTL [7]. Even if none of the UE measurement is reported from a cell, it is not eliminated during at least the TTL. Therefore, the length of the TTL is a major factor for accurate NCL maintenance. A properly selected TTL needs to be employed depending on the network environment such as cell types and the number of UEs. For instance, to avoid eliminating a true neighbor cell on the list, a relatively long TTL needs to be selected when UE measurement reporting is infrequent.

IV. PCI ALLOCATION

During the PCI allocation, PCI collision needs to be avoided. The PCI-collision condition is satisfied when two neighbor cells use an identical PCI, which may restrict the UEs' communications with any eNBs. PCI-collision also occurs when any of the neighbor cells (more than one) of a cell use an identical PCI. Therefore, two neighbor cells have to use different PCIs and the cells in the neighbor relation of a cell should not share a PCI, to avoid PCI collision.

A. The Scheme

A candidate PCI list needs to be constructed from available PCIs where collision-causing PCIs are eliminated. Eliminating the collision-causing PCIs of neighbor cells is based on UE measurement. Therefore, the accuracy of the list may depend on many factors such as the number of UEs and their distribution pattern in overlapping coverage areas [10], [11].

A newly deployed eNB collects the RSRPs of the cells in the PCI list. The RSRP is measured usually by the UE, but additionally installed down-link receivers in the newly deployed eNB (i.e., eNB scanning) may perform similarly to UE measurement [1], [12]. The PCI of a cell whose RSRP satisfies the following

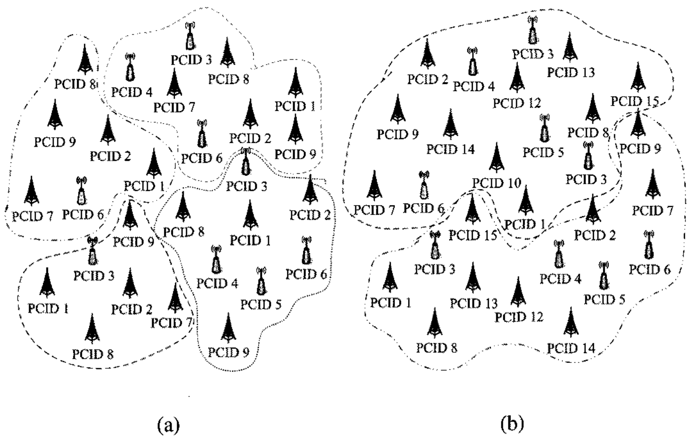


Fig. 6. PCI reuse pattern by controlling α: (a) Large α and (b) small α.

condition is selected for the newly installed eNB.

$$\mathcal{R}_s = \alpha \mathcal{R}_{\max} + (1-\alpha)\mathcal{R}_{\min}, \quad 0 \le \alpha \le 1 \tag{2}$$

where

$$\mathcal{R}_{\max} = \max_{\mathcal{R}_i}\{\mathcal{R}_i | i \in I\}, \tag{3}$$

$$\mathcal{R}_{\min} = \min_{\mathcal{R}_i}\{\mathcal{R}_i | i \in I\}. \tag{4}$$

I is the set of a PCI candidate list, and $\mathcal{R}_i$ is the RSRP received from the cell whose PCI is i. Therefore, $\mathcal{R}_{\max}$ and $\mathcal{R}_{\min}$ denote the maximum and minimum RSRPs of the cells that use the PCIs on the list, respectively. The maximum RSRP of the PCI is selected when $\alpha = 1$ and the minimum RSRP of PCI is selected when $\alpha = 0$. By effectively adjusting α, the geographical distance between two cells that share an identical PCI can be controlled. The maximum value of α, i.e., 1 will result in the minimum distance of the cells that share the same PCI, and a limited number of PCIs can be reused more effectively at the cost of increased chances of PCI collision. On the other hand, employing a small value of α will result in the reduced reusability of the PCI and the probability of PCI collision. Fig. 6 shows the PCI reuse pattern depending on the selected value of α. When a limited number of PCIs are available, a large value of α might be selected at the cost of increased probability of PCI collision.

V. PERFORMANCE EVALUATION

To assess the performance of the proposed self-organizing schemes for the NCL initial configuration and maintenance, and PCI allocation for a newly installed eNB in LTE HetNets, we performed simulations.

A. Simulation Environment

The network layout in the simulations is depicted in Fig. 7. The network consists of regular three-tier hexagonal macro eNBs and 105 picocells. Each macro eNB consists of three-sector cells. Picocell locations are uniformly distributed within

Table 1. System parameters for simulations.

Parameter	Value
Center frequency	2.0 GHz
System bandwidth	10 MHz
Number of macro/pico	37/105
Macrocell Tx power	46 dBm
Picocell Tx power	30 dBm
Macrocell radius	1 km
Picocell radius	150 m
Pathloss (macro) (dB)	$128.1+37.6\times\log_{10}(d\ [\text{km}])$
Pathloss (pico) (dB)	$\begin{cases} 39+20\times\log_{10}(d\ [\text{m}]), & 10\text{m} < d \le 45\ \text{m} \\ -39+67\times\log_{10}(d\ [\text{m}]), & d > 45\ \text{m} \end{cases}$
Log-normal shadowing	Standard deviation(macro/pico) = 8 dB/10 dB de-correlation distance = 50 m
Antenna gain	14 dBi (macro)/5 dBi (pico)
Antenna pattern (macro)	$A(\theta) = -\min\left[12\left(\frac{\theta}{\theta_{3\ \text{dB}}}\right)^2, A_m\right]$ $\theta_{3\ \text{dB}} = 70°, A_m = 20\ \text{dB}$
Antenna pattern (pico)	Omnidirectional
Thermal noise density	– 174 dBm/Hz
Minimum distance between a macrocell and a pico cell	100 m
Minimum distance between picocells	50 m
UE speed	60 km/h
UE measurement period	200 ms

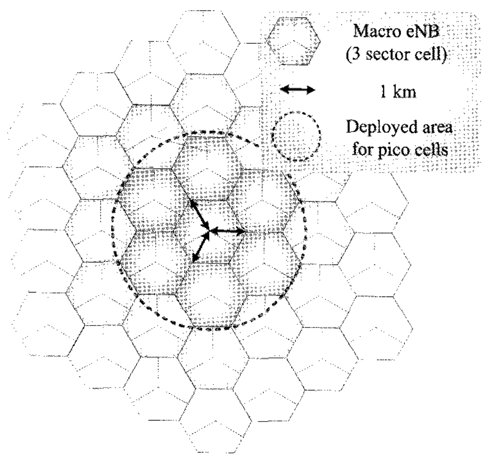


Fig. 7. Macro/pico cell layout.

the circle as depicted in Fig. 7. The channel is modeled considering the path-loss and log-normal shadowing, and the system parameters for the simulations are listed in Table 1, and are based on [13] and [14].

B. Initial NCL Configuration

We compute the "NCL detection probability (DP)" and "NCL false alarm rate (FAR)" by comparing the obtained NCL and the ideal NCL. The NCL DP is defined as the ratio of correctly selected neighbor cells to the total number of the neighbor cells in the ideal NCL. The NCL FAR is defined as the ratio of the "number of non-neighbor cells" that are erroneously selected to the "total number of neighbor cells" included in the obtained NCL. Furthermore, as the measure of HO performance that is significantly affected by the obtained NCL, we consider the "HO delay area ratio." The HO delay area ratio is the sum of HO areas that are excluded according to the NCL to the total HO area. Therefore, if the NCL includes the complete neighbor cells, then the HO delay area ratio will be zero. This measure is an indirect way to assess the performance of the obtained NCL at the initial state before any UEs are activated in the network. In the scenario that a macro eNB is installed in the macrocell layout (we refer to this scenario as "macro-macro" or "MM," and the other scenarios are referred to in a similar manner), a new macro sector cell basically overlaps the coverage with six adjacent cells, as shown in Fig. 7. In addition, about four more cells in the outer-tier become neighbor cells due to the shadowing effect. Generally, macro sector cells have more ideal neighbor cells than picocells due to their large coverage size. The initial NCL performance in the macro-macro scenario is shown in Fig. 8(a). All of the ideal macro neighbor cells are included in the initial NCL when the SINR threshold is set equal to or below −45 dB. However, the NCL FAR becomes higher than 85% and many unnecessary macro sector cells are contained in the NCL. If we set the SINR threshold above 0 dB, then the eNB scanner cannot add any macro neighbor cells to the NCL, and

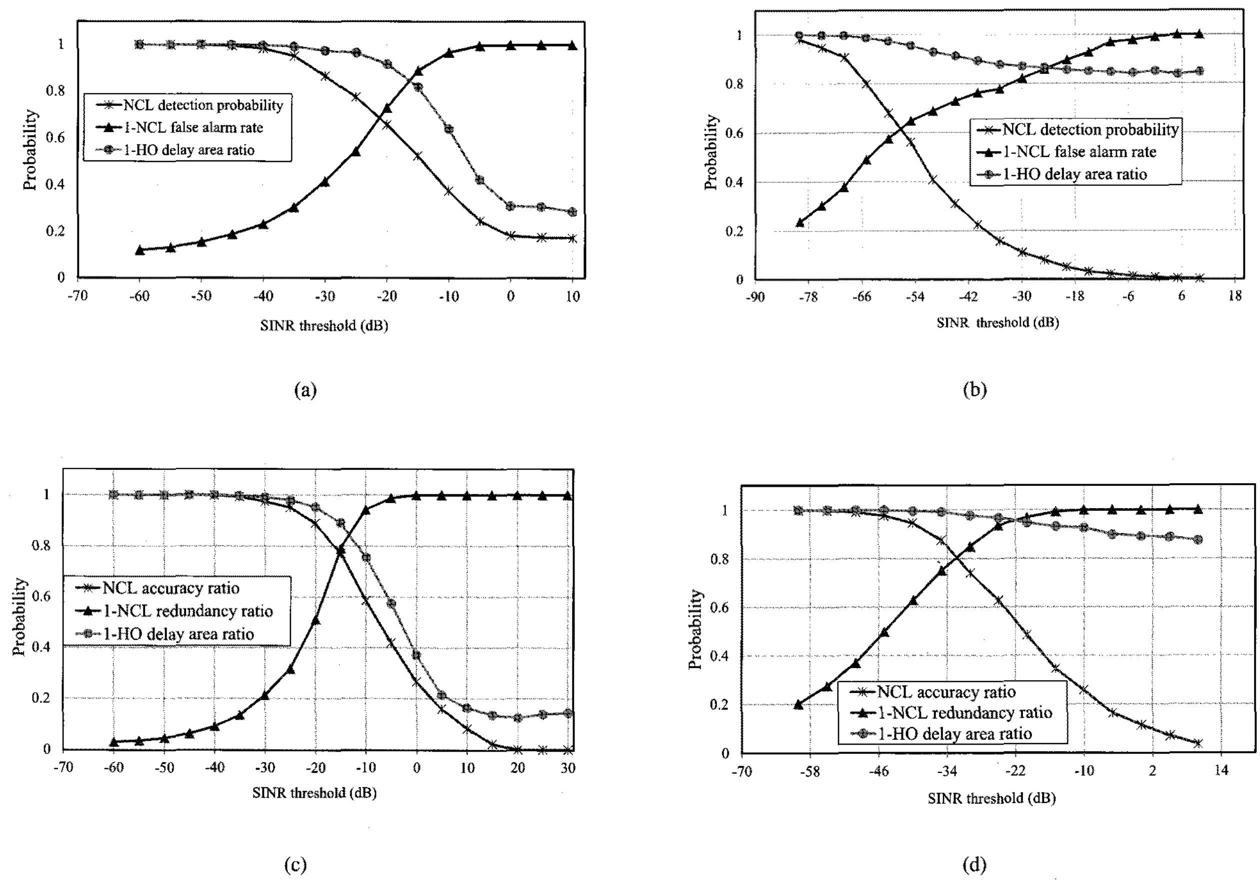


Fig. 8. Initial NCL performance according to SINR threshold: (a) Macro-macro, (b) macro-pico, (c) pico-macro, and (d) pico-pico.

only two macro sector cells that share the same eNB are contained in the NCL. Fig. 8(b) shows the result of the macro-pico scenario. It shows that a new macro sector cell needs to detect the broadcasted signal whose SINR is even lower than −80dB in order to add all ideal pico neighbor cells to the NCL. However, −80 dB might be too low to decode the identifier information, and we need a complementary manner to add the weak-signal-transmitting neighbor pico cells: after the newly installed macro eNB adds the detectable (greater than −80 dB) pico neighbor cells to the NCL, the identifiers of the weak-signal-transmitting neighbor cells can be transferred through the detected neighbor picocells on condition that they are also neighbors to each other. Figs. 8(c) and 8(d) show the performance of self-configuration of the initial NCL in the pico-macro and pico-pico scenarios, respectively. They show that the SINR threshold that achieves an NCL DP of over 90% is higher than that in the scenario when the new eNB is the macro type. This is because a new picocell forms a small coverage area; thus, handover candidate cells are very closely located to it. Therefore, the measured SINR is relatively high when eNB scanning is performed by the picocell. Note that the crossing point of DP and 1-FAR (we hereafter refer to this as complement FAR, or CFAR) is higher (around 0.8) compared to the case when a macrocell is newly deployed (below 0.7).

In order to configure the optimum initial NCL, we should increase the NCL DP and decrease the NCL FAR. The eNB scanning is an effective method to obtain the information of the adjacent cells in the pre-operational state. However, it is difficult to reflect the features of the cell boundary region where handover may occur. Accordingly, it may not be possible to achieve the ideal NCL whose NCL DP is 100% and NCL FAR is 0% based on eNB scanning. Because the both quantities are in a tradeoff relation, we have to select the proper SINR threshold depending on the priority of the ratios. When the NCL length increase, the handover delay problem more seriously damages the system performance than the increased system overhead. Therefore, the SINR threshold that is lower than the ideal needs to be

Table 2. Maximized NCL performance and corresponding SINR thresholds. The values of DP+CFAR in parentheses are based on the distance threshold scheme.

Scenario type	MM	MP	PM	PP
SINR threshold	−20 dB	−65 dB	−15 dB	−35 dB
Distance threshold	(2.5 km)	(1.6 km)	(1.4 km)	(0.3 km)
DP+CFAR	1.39 (1.26)	1.29 (1.18)	1.56 (1.20)	1.63 (1.76)

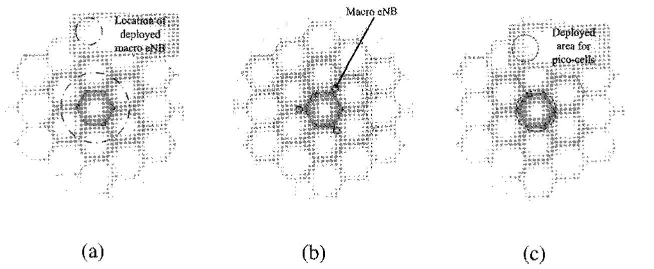


Fig. 9. Newly installed eNBs: (a) Macro-macro scenario, (b) pico-macro scenario, and (c) macro-pico and pico-pico scenarios.

selected for improved handover performance. If we assume the same weighting factor for DP and FAR, we can select the threshold SINR that maximizes the sum of DP and CFAR in order to maximize the performance. The threshold SINRs that maximize the performance are summarized in Table 2. The performance based on the geographical distance threshold is also compared in the table. The results in Table 2 show that the eNB scanning approach outperforms the conventional distance-threshold-based approach by at least 9.3%, except for the PP scenario, particularly in the HetNet scenarios (i.e., MP and PM cases).

C. NCL Maintenance

In the simulations, to make the change in the neighbor cell configuration, an eNB is installed at a certain moment. The type and location of the newly deployed eNB follows four different scenarios as shown in Fig. 9. UEs are generated within 2.6 km from the center, and UE measurement is performed every 200 ms. Handover is performed based on the SINRs of the cells.

C.1 Adding Scheme Performance

At first, in the MM scenario, a macro eNB is installed at the 1000th measurement iteration. The NCL DP performance shows different results depending on the average number of UEs per sector cell, as shown in Fig. 10(a). It shows higher detection probability when more UEs are activated. On the other hand, FAR shows a similar performance regardless of the number of UEs in the same scenario, as shown in Fig. 10(b). Therefore, an increased number of UEs enhances the performance of the adding scheme.

Depending on the coverage characteristic following the cell type scenarios, the performance of the NCL adding scheme varies, as shown in Fig. 11. The results show that the performance is retrieved slowly or is poorer when the serving cell is a picocell compared to that when the serving cell is a macrocell. This is because the lower number of UEs in the overlapping coverage area report measurements less frequently when the serving cell is the picocell.

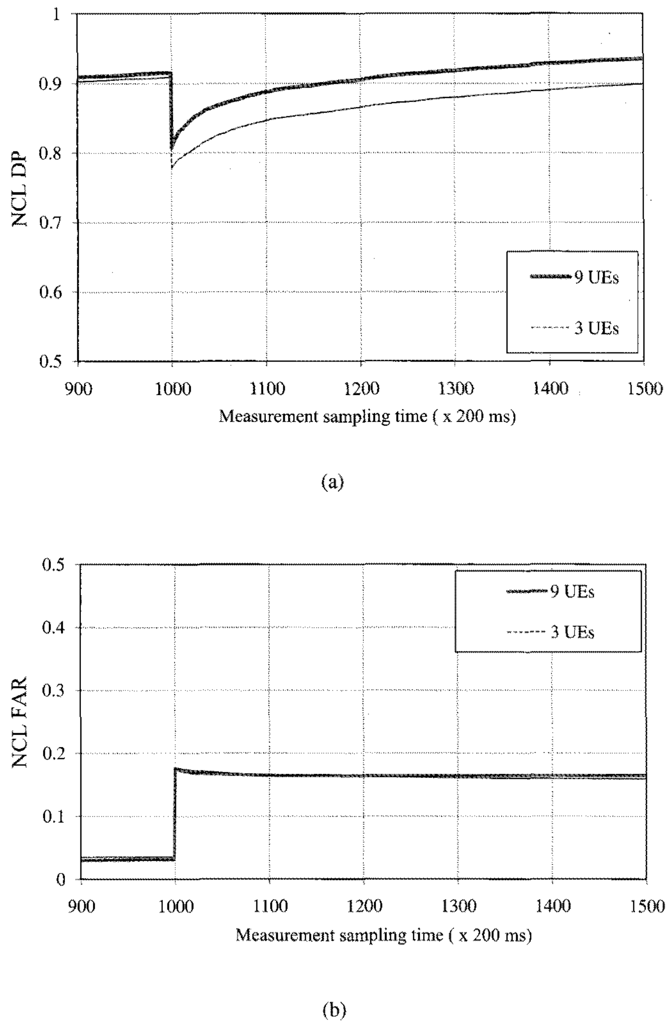


Fig. 10. Adding scheme performance in macro-macro scenario depending on the average number of UEs per sector cell: (a) NCL detection probability and (b) NCL false alarm rate.

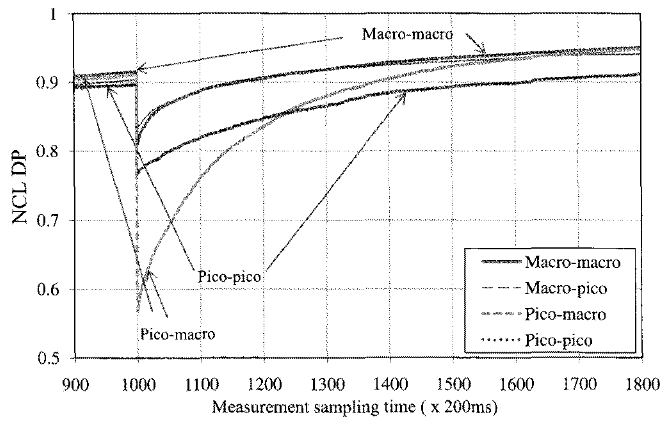
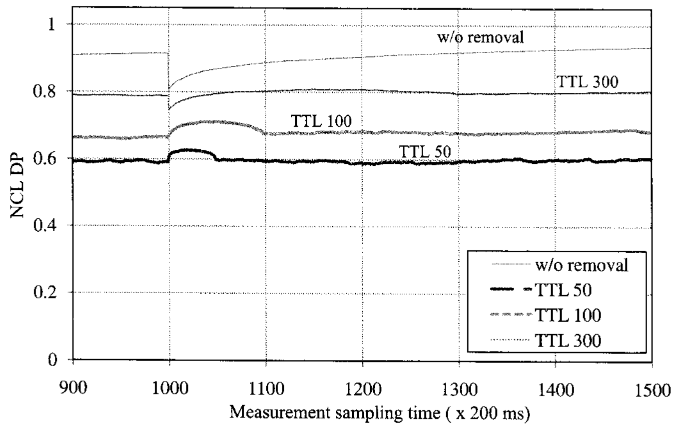


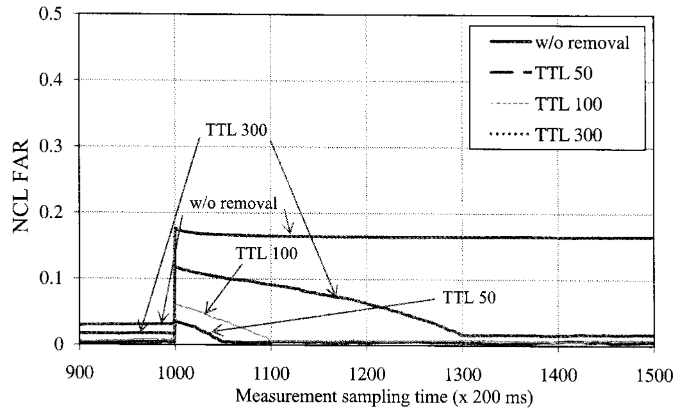
Fig. 11. NCL detection probability for various cell type scenarios.

C.2 Eliminating Scheme Performance

NCL performance employing the eliminating scheme in addition to the adding scheme is investigated. The performance of the NCL eliminating scheme primarily depends on the TTL length. When a short TTL is employed, the cells whose UE measurements are not frequent enough will be eliminated from the NCL. The shorter the employed TTL, the lower the detection



(a)



(b)

Fig. 12. Eliminating scheme performance in macro-macro scenario depending on TTL: (a) NCL detection probability and (b) NCL false alarm rate.

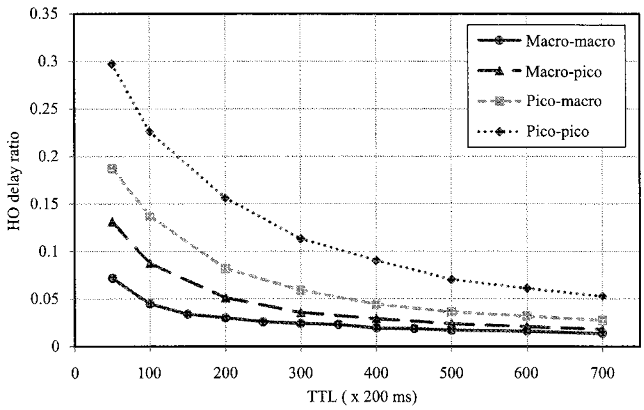


Fig. 13. Handover delay ratio depending on TTL and HetNets type.

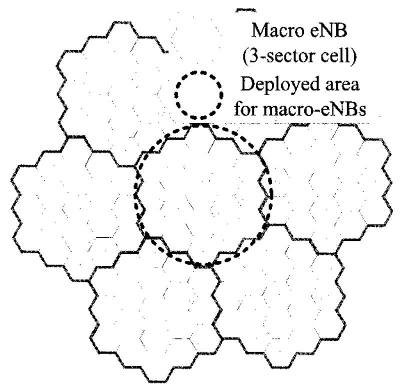


Fig. 14. Cell layout and installed additional macro-eNBs of the 19 cluster case.

Table 3. TTL for handover delay ratio below 5%.

Macro-macro	Macro-pico	Pico-macro	Pico-pico
100 iterations	200 iterations	400 iterations	700 iterations

probability, as shown in Fig. 12(a), where the MM scenario is considered. On the other hand, by employing the eliminating scheme, highly enhanced FAR performance can be achieved as shown in Fig. 12(b). FAR is diminished from 0.17 up to 0.02 by the eliminating scheme. To acquire a similar handover delay performance, TTL values need to be carefully selected depending on the HetNet type. Since the handover delay is directly related to the NCL DP performance, the handover delay performance tends to be degraded when a picocell is the serving cell. Accordingly, a relatively longer TTL value needs to be employed for a pico serving cell to acquire similar performance to that in the case of a macro serving cell as shown in Fig. 13. TTL values for a handover delay ratio below 5% for each HetNets scenario are summarized in Table 3, where the handover delay ratio is computed by the number of delayed handovers over the number of total handovers attempted.

D. PCI Allocation

The cell layout for the simulations is the same as that in Fig. 7, and we consider two cases. Given the cell layout, macro-eNBs or pico-eNBs are installed, and we compare the performance with that of random selection (as in the technical specification) from the PCI list. The PCIs are allocated to additionally installed eNBs consecutively. The 504 PCIs are exclusively divided for macro and pico eNBs to prevent PCI collision in advance [15]. When an additional eNB is the macro-type, it is deployed within the central cluster of 19, as shown in Fig. 14. The PCIs are reused by cluster. Three PCIs are allocated to each macro eNB for three sectors. When an additional eNB is the pico-type, the deployed scenario is the same as that shown in Fig. 9(c), and the average number of deployed pico-eNBs per sector is 20.

The required numbers of additional PCIs are shown in Fig. 15 upon the installation of additional eNBs of the macro-type. The cluster size is 19, and three PCIs are additionally allocated when a PCI is not available for a newly installed eNB. In this case, we use the ideal NCL for the newly installed eNBs, and consequently, PCI collision is avoided in advance. Fig. 15 shows

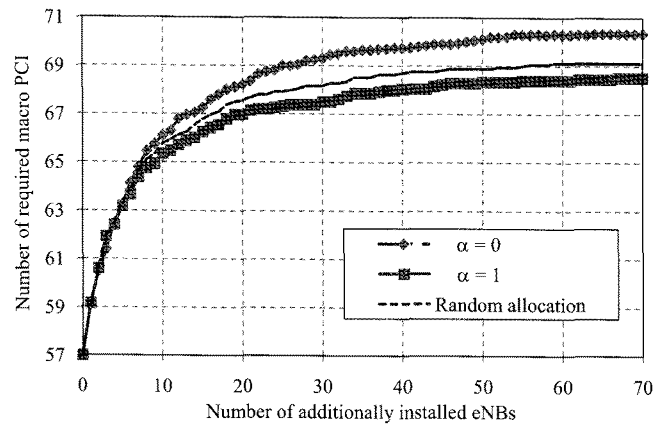


Fig. 15. Number of additionally required PCIs when macro-eNBs are additionally installed.

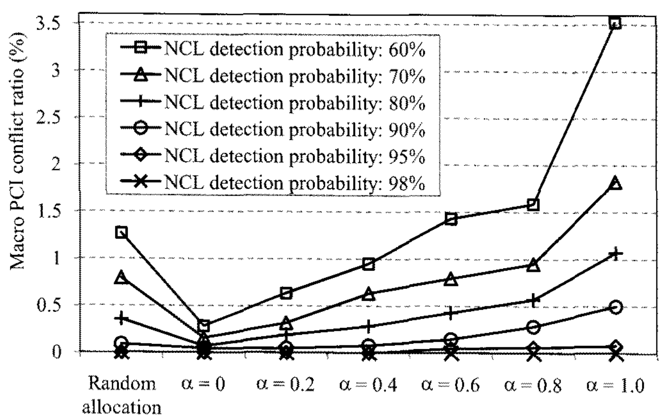


Fig. 16. Macro-eNB conflict ratio according to NCL detection probability and α.

that the required numbers of additional PCIs are minimum when $\alpha = 1$, although the difference is not significant. Since the cell layout has a regular pattern and the PCIs are reused by cluster, the PCI candidate list for each scheme is similar. Therefore, the proposed scheme is not very different from the random allocation scheme in performance.

Next, we consider the case when the NCL is not ideal. That is, the NCLs of newly deployed eNBs do not have the features that DP is 1 and FAR is 0. The PCI collision ratios are shown according to the NCL detection probability and α in Fig. 16. The smaller the α, the lower the conflict ratio. Specifically, when α is 0, 0.2, and 0.4, the conflict ratio is diminished by 80%, 60%, and 25%, respectively.

Fig. 17 shows the PCI shortage ratio depending on the number of allocated PCIs to pico-eNBs when additionally installed eNBs are the pico-type. In this case, the ideal NCL is employed, and consequently, PCI conflict is avoided. The performance pattern that results is similar to the macro-type case. From the result, we need to allocate at least 38 PCIs for pico-eNBs to avoid PCI shortage in this simulation scenario. However, 46 PCIs are still not enough when random allocation is employed. We consider the PCI conflict ratio of installed pico-eNBs depending on not the NCL DP, but on the cell-types of neighbor cells because

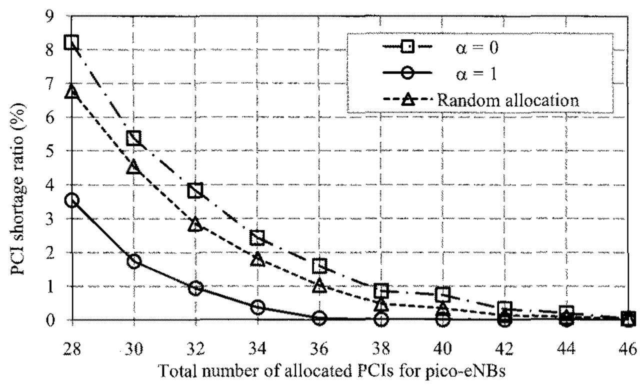


Fig. 17. PCI shortage ratio according to the total number of allocated PCIs for pico-eNBs.

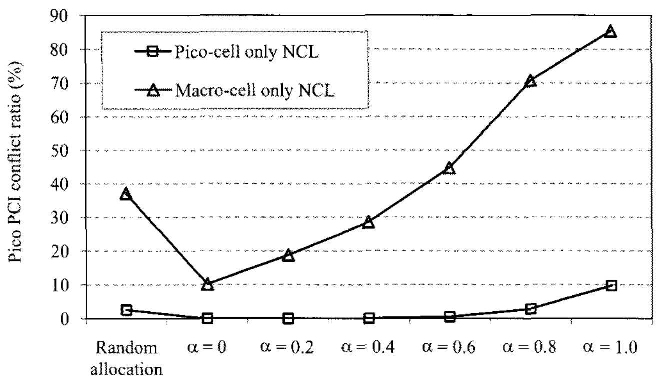


Fig. 18. Pico-PCI conflict ratio depending on the cell-type on NCL.

the performance is significantly different depending on whether a neighbor cell is the macro-type or the pico-type. When a neighbor is a macrocell, its own NCL information significantly mitigates the conflict ratio due to wide coverage and relatively more pico-neighbor cells than in the case when a picocell is neighboring. Fig. 18 shows the conflict ratio when additional pico-eNBs are installed, by using only a single type of neighbor cells from the ideal NCL. The result shows performance pattern similar to the the macro-eNB case. The conflict ratio can be reduced to zero when an NCL is full of only macrocells. In both cases, the ratio is better when $\alpha = 0, 0.2$, and 0.4 than that of random allocation. In particular, the ratio is mitigated by 73%, 49%, and 23%, respectively, when an NCL is full of picocells only.

VI. SUMMARY AND CONCLUSION

In this paper, we investigated self-organizing schemes in HetNets environment such as LTE-advanced systems. In particular, we focused on the management of the initial NCL and its maintenance, and efficient PCI allocation based on eNB scanning and UE measurement. Self-configured initial NCL performance was compared to that of the traditional distance-threshold-based scheme, and overall, the proposed scheme showed better performance, particularly in PM and MP HetNets at least by 9.3%. This self-organizing scheme based on eNB scanning for initial NCL configuration becomes the basis for the consequent maintenance scheme by which more accurate NCL updating is managed. In the maintenance scheme of an NCL, UE measurement was employed rather than eNB scanning since activated UEs are available. As the number of UEs increase, the performance is improved, and accordingly, the performance is degraded when a picocell is the serving cell. Depending on HetNets types, the TTL value needs to be carefully selected in the cell eliminating scheme, and a relatively longer TTL needs to be selected when a picocell is the serving cell for satisfactory handover performance. In the PCI allocation scheme, the PCI conflict ratio can be controlled and diminished by adjusting the parameter α. The performance was compared with that of the random allocation scheme that was suggested in the LTE technical specification, and showed outperforming results when a properly selected α was employed. This efficient PCI allocation scheme based on eNB scanning can be employed for newly installed eNBs as occasion demands without additional PCIs.

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