Layer-Independent PCI Assignment Method for Ultra-Dense Multi-Layer Co-Channel Mobile Networks

Stephen S. Mwanje, Janne Ali-Tolppa
Nokia Bell Labs, Munich, Germany
Email: {stephen.mwanje; janne.ali-tolppa}@nokia-bell-labs.com

***Abstract*—Ultra-Dense Networks (UDNs) are Heterogeneous Networks (HetNets) that deploy a high density of small cells over-laying the traditional macro cells. If several Long Term Evolution (LTE) layers share the available spectrum, assigning the Physical Cell Identities (PCIs) becomes complicated due to the density and the diversity of the network. Since different layers can be managed by different Network Management (NM) and Self-Organizing Network (SON) solutions, it would often be desirable to be able to assign the PCIs in each layer independently. At the same time it must be ensured that the PCI conflicts, also between the layers, are minimized. When the small cell layer is managed independently, high cell density increases the probability that two small cells sharing the same PCI are neighbors to the same macro cell, thereby creating a conflict in inter-layer adjacencies, even when within the layers PCI conflicts are avoided. We propose a method that can minimize these inter-layer conflicts, while still allowing independent assignment between the layers. Starting with an initial intelligent guess for adequate PCI reuse distance, the solution then uses the Automatic Neighbor Relation (ANR) function to learn the full multi-layer network topology and optimize the PCI assignment. Comparing with state of the art strategies, our results show that the proposed approach maintains good performance without requiring the exchange of information across layers.**

I. Introduction

Demands for higher user throughput for mobile broadband applications can be met by shortening the spectrum re-use distance with denser base station deployments. The result is a Heterogeneous Network (HetNet) in which an overlay of small cells (micro, pico or femto cells) is deployed over the traditional macro cells. The overlay, hereinafter also interchangeably called the small cell layer or simply the pico layer, may use the same Radio Access Technology (RAT) or different RATs. To guarantee even higher throughput requirements requires even denser cell deployments, leading to Ultra-Dense Networks (UDNs).

In dense, multi-layer Long Term Evolution (LTE) deployments, Physical Cell Identity (PCI) assignment becomes a complex task, when the layers share the same frequency. PCIs are used for example by the User Equipment (UE) for searching cells to camp on or to identify neighbor cells for cells re-selection and handover. The well-known problem in allocating PCI is that since there are only a limited number of PCI values available (504 in an LTE network), the PCIs must be reused. At the same time, however, there are constraints for the PCI assignment. For example, no two neighboring cells, or two cells sharing a same neighbor, must use the same PCI value. In multi-layer, co-channel deployments these constraints need to be satisfied not only within the layers, but also in inter-layer cell neighbor relationships.

The main complexity in such deployments comes from two contradicting requirements. First, it is desirable to assign the PCIs separately for each layer, in order for not to need to share Network Management (NM) information between them. This would require advanced features from the small cell layer, in case it is not managed by the same NM solution as the macros, and can often mean multi-vendor integration. On the other hand, we must ensure optimal performance, i.e., that the PCI conflicts are, as much as possible, minimized.

PCI auto-configuration is a widely studied topic within Self-Organizing Networks (SONs) and studies have concluded that PCIs can be assigned in an automated and conflict free way, even when layers are assigned independently [1]–[6]. This is, however, because they only considered the currently deployed low density HetNets with few (up to three) small cells per macro and in few hot-spots [5].

In practice, networks will get denser to 6-sector macro cells and more than 3 small cells per macro. In our previous work [7], we studied how the current methods can cope with these denser deployments. We showed that in co-channel UDNs assigning each layer independently with state of the art methods becomes impossible without compromising the PCI integrity in inter-layer adjacencies. Especially the number of PCI confusions increases dramatically, since often two small cells with the same PCI (equi-PCI cells) are both neighbors to the same macro cell.

In this paper we propose a layer-independent PCI assignment method for ultra-dense multi-layer co-channel networks, which mitigates the problems highlighted in our previous work. Starting with an initial intelligent guess on the minimum PCI reuse distance, we allocate PCIs independently using a split PCI range with a separate subrange reserved for each layer. Then, using the Automatic Neighbor Relation (ANR) procedure [8], the solution learns the network topology (including the PCIs of inter-layer neighboring cells) and subsequently optimizes the PCI assignments. Comparing its performance against the simple split range approach, we

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show that our approach maintains good performance without requiring exchange of information across the layers.

The rest of the paper is structured as follows. Section II provides the necessary background for the PCI assignment problem and reviews the objectives and strategies. Section III reviews the relevant related work done on PCI auto-configuration and highlights the problems discovered in [7]. Section IV describes the proposed improved approach. Section V explains the scenario and methods used to evaluate the concept, while Section VI presents the evaluation results and compares them to the previous range separation approaches. Finally, we end with conclusive remarks in section VII.

II. PCI Assignment Requirements and Strategies

PCI assignment objectives are comprehensively discussed in [7], but we review them here briefly for completeness. A PCI is a combination of a cell's physical-layer cell-identity group N_{ID}^1 and its physical-layer cell identity N_{ID}^2, as given by equation 1.

$$PCI = 3 * N_{ID}^1 + N_{ID}^2 \quad (1)$$

There are 168 physical-layer cell-identity groups each containing three unique physical-layer cell identities, leading to 504 available PCI values. Each PCI value is related to the cell's Primary Synchronization Signal (PSS) and to the Secondary Synchronization Signal (SSS), which is characterized by two indices m_0 and m_1. In addition, the PCI has a dependency to the reference signals, whose indexes are defined by the so-called modulo rules (mod 3/6/30) [7] [9].

A. PCI Assignment Objectives

Although seemingly simple, PCI assignment is not trivial owing to the limited number of available values and the need to minimize conflicting PCI values between neighboring cells. With limited PCIs, values inevitable need to be reused. Consequently, a good assignment should ensure to:

1) *Minimize the need for PCI reconfigurations:* Reconfiguration often requires a restart and therefore can be done only within a maintenance window.
2) *Minimize the number of PCI used:* This ensures extendability of the network, i.e. it is possible to carve out ID space for additional network layers without having to make extensive PCI reconfigurations in the existing network. This will lead to degraded service quality if a sub-optimal configuration has to wait for such a window to be changed.
3) *Avoid PCI collisions:* A collision occurs if two neighboring cells have the same PCI (Fig. 1a). A UE cannot distinguish between the two cells, potentially leading to a handover (HO) failure.
4) *Avoid PCI confusions:* A confusion occurs if two cells C1, C2 that are both neighbors to the same cell C3, are assigned the same PCI, as in Fig. 1b. C3 cannot distinguish the HO measurements of C1 and C2 and is unable to determine, which cell to hand a UE over to.
5) *Avoid (or at least minimize) m_0 and m_1 conflicts:* For two neighbor cells C1, C2, even if their PCIs P1, P2 are different, it is possible that one of the SSS root indices (m_0 or m_1) for the two PCIs is the same. If P1 and P2 have the same m_0 or m_1(e.g., PCIs 1, 31, 60, 88, .. with m_0=1 and 5, 34, 62, 89, .. with m_1=6), part of the SSSs will be similar. Then, at low Signal to Interference plus Noise Ratio (SINR), a UE will have difficulty differentiating the SSSs (and thus the PCIs), resulting in a long synchronization time for the UE.
6) *Avoid (or minimize) reference signal interference:* Cells with equal *PCI mod 3/6/30* (Fig. 1c) have higher co-interference among them. As a minimum, it is desirable that *PCI mod 3/6* are dissimilar among co-site cells (cells on the same site) and that *PCI mod 30* is dissimilar among any potentially interfering cells. The desirable condition that *PCI mod 3/6* are dissimilar among non co-site cells is practically hard to achieve, especially in HetNet scenarios and is thus not considered hereafter.

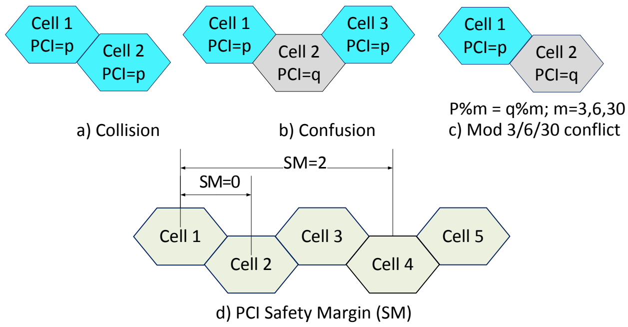

Fig. 1. Critical PCI conflicts and the Safety Margins (SM)

PCI conflicts are typically avoided by defining a Safety Margin (SM), which is the minimum number of cells between two cells C1 and C2 sharing the same PCI value. E.g., as showed in Fig. 1d, if SM is set to zero, direct neighbors may share the same PCI, while SM=2, the minimum required for confusion free assignment, leaves two cells between C1 and C2. Meanwhile, a larger SM (>2) is often necessary to allow for network extension. For example, if more cells will be added to the network after initial deployment, a larger SM allows a PCI to be assigned to the new cells without changing PCIs of the existing cells.

B. PCI assignment strategies

Existing solutions show that the initial PCI assignment is a graph coloring problem [10] and all the initial HetNet assignment strategies in these solutions fall in one of two alternatives:

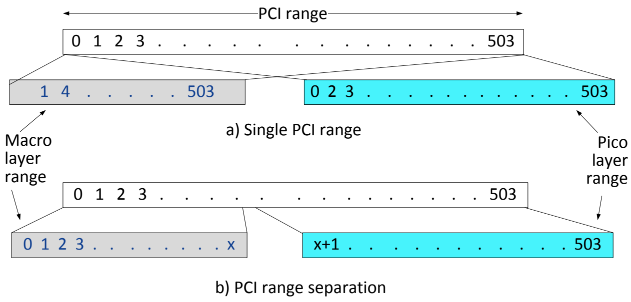

Fig. 2. PCI assignment strategies

1) Single PCI range: In this case, as illustrated in Fig. 2a, the entire PCI range is used to assign PCIs in all layers. This was used in single layer studies [1]–[3] and in some HetNet solutions [4]. In this approach, each layer requires full information about assignments in other layer(s) in order to avoid conflicts in inter-layer neighbor relationships. This is not always possible, since the layers may be from different vendors with different PCI assignment solutions. Meanwhile, starting with LTE, cells are typically expected to have X2 interfaces - the direct cell-cell interface for information exchange between cells - through which one cell may be able to query another for the respective Neighbor Relationships (NRs) and applied PCI. This may, however, not be true for small cells since this may be lead to a dense mesh of X2 links increases the deployment cost of small cells. Single range PCI assignment thus becomes inapplicable for multi-layer deployments

2) Range separation: This strategy splits the PCI range a priori into subranges, allocating one subrange per cell layer, as illustrated in Fig. 2b) [5]. Each layer can be assigned independently without sharing information across layers, since cells are only assigned PCIs from the corresponding layer's subrange. However, the subranges (the value of x in Fig. 2b) cannot be adjusted at runtime without extensively reassigning PCIs in multiple cells, yet PCIs could easily be exhausted in one layer while they are underutilized in the other. Moreover, confusion-free assignment in each layer, does not guarantee the same across layers. In other words, range separation can only assure that there are no PCI collisions across layers, but cannot guarantee satisfying any of the other constraints.

III. Related Work

Within the context of SONs [8] [11], PCI auto-configuration has been widely studied (e.g. in [1]–[6]) as a graph coloring problem. In these methods the network topology is modeled as a graph and with certain adoptions the PCI assignment can be reduced to the well-known problem of coloring the graph nodes so that no connected nodes share the same color [10]. Most studies considered the initial configuration use case of assigning PCIs to a newly installed network, although some (e.g. [1] [6]) study the specific case of adding new cells to operational networks. Meanwhile, the earliest work in [1]–[3] studied the fairly trivial one layer case. However, recent work, e.g., [5], studied the more challenging HetNet scenario, with an intent to find a compromise between two conflicting objectives: 1) splitting the PCI range so as to independently assign each layer, and 2) having a complete picture of the network to ensure avoiding PCI conflicts, which then requires sharing information across the layers.

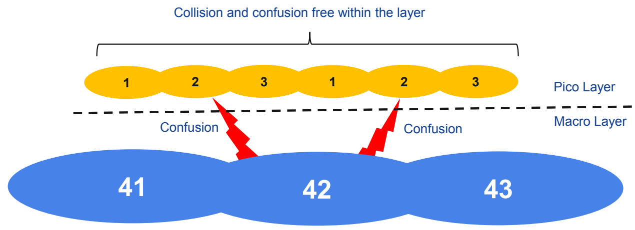

Fig. 3. An example of an inter-layer PCI confusion, when there are now confusions within either layer

The studies above concluded that PCIs can be assigned in an automated and conflict free way, even when layers are assigned independently. This, however, is because they only considered the currently deployed low density HetNets with few (up to three) small cells per macro and in few hot-spots [5]. Other studies, e.g. [3], assign the pico layer PCIs, but ignore any possible macro layer sharing the same spectrum. Even where it is considered, the assumed macro cells density is low, typically 3 sectors per macro, as in [4].

As extensively discussed in our previous work [7], the limitations in current HetNet PCI allocation strategies cause significant problems in ultra-dense co-channel HetNet deployments. The split range strategy can only prevent collision between the layers, but not satisfy any of the other PCI assignment constraints, most importantly preventing PCI confusions between the layers, as shown in Fig. 3. Therefore, either one solution is required to managed the PCIs of all of the layers or the NM solutions of each layer must exchange information on their complete network topologies, including the PCIs. This is, as stated before, often expensive and difficult to achieve, since the macro and the small cells layers can be from different vendors. An alternative approach is thus required.

IV. Proposed PCI Assignment Approach

We assume for a network with a macro and a (typically independent) pico layer that:

1) the pico layer cells do not have access to macro layer NRs. Such is the case, when pico cells have no X2 interface and so cannot request the information from their neighbors
2) pico layer Operation, Administration and Management (OAM) systems do not know macro NRs, a typical case when the two layers are supplied by different vendors with incompatible OAM systems
3) the PCI range is separated into subranges, one for each layer.

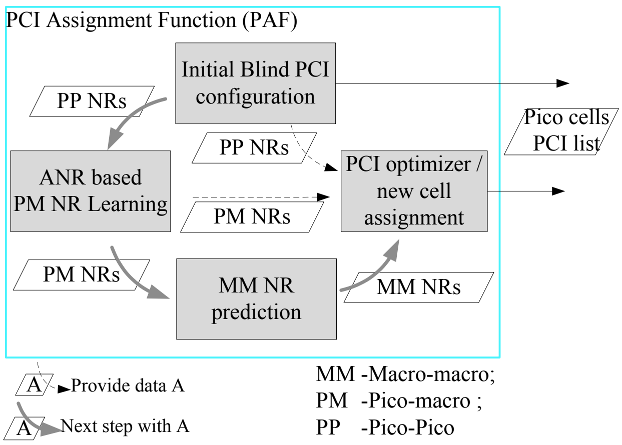

Fig. 4. The PCI Assignment Function (PAF)

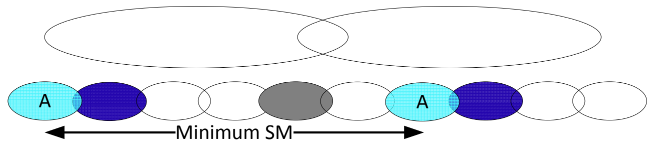

Fig. 5. Minimum safety margin for blind assignment

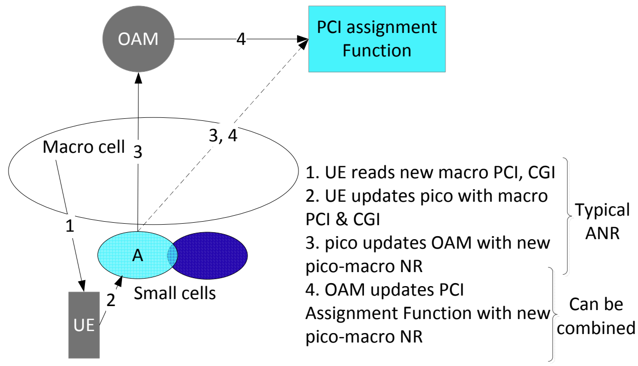

Fig. 6. Learning macro cells' neighbor relations

Our proposed PCI Assignment Function (PAF) is shown in Fig. 4. The PAF has 4 sub-functions, one for each of 4 sequential processes. First, it blindly assigns (or configures) PCIs to the pico layer cells with each cell independently assigned. It then learns the actual NRs, beginning with the pico-macro NRs and then learning the macro-macro NRs using the learned pico-macro NRs. Lastly, it optimizes the PCIs assignments using the full graph of NRs as learned in the previous steps. The full operation of each of the processes is as follows:

A. Initial blind assignment

For the initial pico layer configuration, the PAF blindly assigns PCIs to all pico cells from the pico layer PCI range, ensuring that PCIs are re-used far apart enough that there are no PCI confusions. The problem here is on deciding the appropriate safety margin so that PCI confusions are avoided, but yet PCIs are assigned efficiently and not wasted. This is estimated utilizing the expected macro cell coverage radius/distance, or simply the macro cell radius and the pico cells Inter-Site Distance (ISD). For confusion free assignment, the pico SM is set according to equation 2.

$$SM \geq \frac{MacroCell\ Radius}{SmallCell\ ISD} + 2 \tag{2}$$

Equation 2 fulfills the minimum requirement for confusion free assignment, i.e., that no two equi-PCI pico cells should be neighbors to the same macro cell. This is shown in Fig. 5 where it is ensured that the two equi-PCI pico cells marked A are not neighbors to the same macro cell. For pico islands, i.e. subnetworks of pico cells which are not connected to other cells in the pico layer with an adjacency, the reuse distance is determined using geography, i.e., a PCI is reused in two cells if the distance d between them is

$$d \geq MacroCell\ Radius + 2 \cdot SmallCell\ ISD \tag{3}$$

The assignment uses a pico-pico NRs graph, in which NRs are obtained by applying geometry and radio prediction rules (similar to those used in network planning tools) to select the pico cells that are likely to be neighbors.

B. Learning pico-macro NRs

After the pico PCIs have been blindly allocated, the PAF needs to learn the actual macro PCIs in order to optimize the initial allocation and make optimal new assignments, when needed. The macro PCIs are learned during operation from information provided by the ANR process [8], through which unknown NRs for a given cell are learned. As shown in Fig. 6, each pico cell learns its macro NRs by requesting its associated UEs to read the neighbor cells' PCI and Cell Global Identity (CGI) after which it updates OAM with the newly learned NR (steps 1-3). This is the standard ANR procedure to which a new step is added to achieve the desired objective. In this last step (step 4), the OAM updates the PAF with the new pico-macro NR. Note however, that the final updates can be combined by having each pico cell directly update the PAF with the new pico-macro NRs as soon as they are learned.

C. Predict macro-macro NRs using the known pico-macro NRs

In order to enable later extension of the network with new cells, the used Safety Margin (SM) must be sufficiently large in consideration of the potential cell additions. In addition, the SM must take into account extensions in either pico or in the macro layer, which requires complete knowledge of all NRs at the PAF. Thus, macro-macro NRs need to be derived for the pico layer.

Using the list of pico-macro NRs (as learned according to subsection IV-B above), the macro-macro NRs can be derived from the observation/rule that:

Rule: if two (2) macro cells are neighbors to one pico cell,

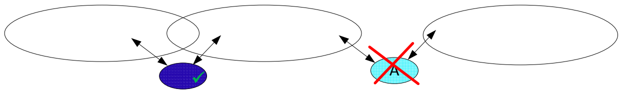

Fig. 7. Determining macro cells' NRs based on pico cells NRs

then the two macro cells are neighbors to each other.
As shown in Fig. 7, this rule is derived from the observation that pico cells are so small that they cannot span two macro cells that are not neighbors to one another.

D. PCI update/optimization and new cells configuration

After the learning process, all 3 NR types (pico-pico, pico-macro and macro-macro) will be available to the PAF and a complete NR graph for the network can be constructed from the 3 NR types. Then, applying graph coloring based methods, this complete NR graph can be used to either optimize the initially blindly assigned PCIs or to assign PCIs to new cells that are added to the network. Note that a subset of the complete solution (without the learning function) is possible if pico-macro NRs and macro-macro NRs are available. These NRs can, for example, be derived from macro and pico planning data, if available. Similarly macro-macro NRs could be retrieved from the macro layer OAM system. Either way, the separation of ranges and the availability of the complete NR graph ensures that PCIs are assigned to different layers separately and in a confusion free manner.

V. Evaluation Scenario

The performance of the PAF was evaluated using simulations, since there are no deployments that could be used to study the UDN scenarios needed for the evaluation. Since the scope of the study is to evaluate the PCI assignment strategies, a simplified study scenario was sufficient. Specifically, our simulator, originally described in [7], does not attempt to model the true radio environment, but abstracts the radio characteristics to model the NR graph. We briefly highlight here its critical aspects for completeness. The simulator models co-channel macro and pico cells deployed over a 2x2 km square coverage area. With a macro cell assumed to cover at most 400 m, macro cells are modeled as ellipses with a major diagonal of 400 m (Fig. 8) and a minor diagonal derived from a beamwidth factor that defines the expected beamwidth of the applied antenna, in this case 75^o. Then, with an assumed omni directional coverage of up to 100 m, pico cells are modeled as circles of 100 m radius.

A. Modeling of the NRs

Evaluating the PCI assignment strategies does not require full radio environment simulation, but it is important that NRs are adequately and realistically modeled. For two cells B and K, we assume the following:

- R_B, R_K, R_M and R_P are respectively the radii of cells B and K and maximum coverage distances of a macro cell (400 m) and a pico cell (100 m).

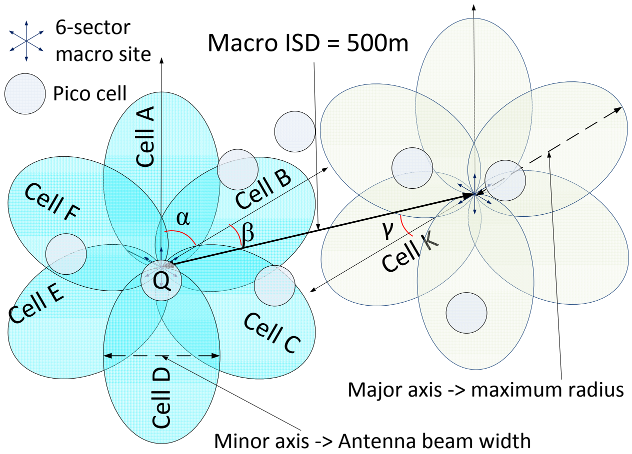

Fig. 8. Cell and network model

- ν_{BK} is the vector from B to K, so that $\nu_{BK} = -\nu_{KB}$;
- $d = |\nu_{BK}|$ is the distance between B and K
- the Beam-factor τ defines the antenna's radiation pattern as the reduction in signal power, relative to the maximum, at a point that is at an angle β from the cell's bore-sight. In effect, for a fixed distance from the antenna, the power reduces by $cos(\beta)^\tau$, which is the rate of roll-off of the ellipse that represents the radio pattern. Here $\tau = 0.75$ *and* 0.0 for the 6-sector macro and the omni directional pico cells respectively.

For the macro cell B, a cell K is considered a neighbor if any of the following is true:

1) K is collocated with B and their directions of radiation differ by no more than 90^o. As such, considering Fig. 8, cells A and C are neighbors to B while cells D, E and F are not.
2) K is not collocated with B but is located within B's coverage area. For an angle β between vector ν_{BK} and the direction of B (Fig. 8), K and B are neighbors if:
$$d < R_M \cdot cos(\beta)^\tau \quad (4)$$
3) K is not collocated with B or located within B's coverage but is close to and (in general) radiating towards B, i.e.
$$d < R_B \cdot cos(\beta)^\tau + R_K \cdot cos(\gamma)^\tau \quad (5)$$
with γ as the angle between K's direction and ν_{KB}. If K is a macro cell, $R_K = R_B = R_M$, otherwise $R_K = R_P$ and γ=0.
4) K is a pico cell and B is located under K's coverage i.e.
$$R_P - d < \epsilon * R_P; \qquad 0 < \epsilon \leq 1. \quad (6)$$
ϵ defines the HO region between B and K as the minimum difference between the pico cell's radius and d, the distance between the two cells. Here we select ϵ=0.2, so that B and K are neighbors if B is at most 80 m from K (e.g. cells Q and B in Fig. 8).

B. PCI assignment

The applied PCI assignment algorithm is graph coloring regardless of the strategy - blind assignment or otherwise. The algorithm takes a list of NRs among cells and generates a graph the nodes of which are the cells and the edges are the NRs. For each node, additional edges are added to all cells, which are within the defined SM. Thus given this graph, if a PCI P is assigned to a cell C1, the scheme ensures to:

1) avoid PCI confusions based on the configured SM, i.e. P is marked as forbidden for all cells that are SM or less neighbors away from C1.
2) avoid mod 30 among direct neighbor cells by marking as forbidden in those cells all PCI values p_i for which $p_i \ mod \ 30 == P \ mod \ 30$.
3) avoid m_0 and m_1 conflicts among direct neighbor cells by marking all PCIs p_i whose m_0 or m_1 are equal to the m_0/m_1 values of P as defined in [9].

It follows from this discussion that the difference between the proposed approach and the range separation strategy is that, besides separating the PCI range into two, range separation does not consider any neighbors in the other layer. Our approach, however, first estimates a suitable reuse distance considering the inter-layer neighbor relationships and then later allows the pico layer to learn the inter-layer and the macro layer NRs and to further optimize its assignments to satisfy the additional constraints.

VI. Results and Discussion

In this section, we compare the performance of the proposed solution to the simple range separation, when applied to two UDN models. The UDN scenarios differ in the density of pico cells, represented by two pico Inter-Site Distances (ISDs) - 100 m and 50 m. In both cases, the macro ISD maintained at 500 m, respectively translating into pico densities of 120 and 470 pico cells per km^2 or 4 and 16 picos per macro in a 6-macro cells per eNB hexagonal grid network. An example of the full deployment for the 100 m pico cell ISD is the network in Fig. 9.

We consider three values for the SM i.e. SM = 2, 3 and 4. The minimum SM of two is selected since, as explained earlier, it is the minimum required for confusion free assignment, at least in any one layer. Note here, however, that for the blind assignment, the specific SM in the pico layer will be selected according to equation 2. For both strategies, with the expectation of an average of 6 to 12 pico cells per macro in the eventual UDN (see [7] for a description of the limits), we divide the PCI range in a way that the macro layer takes the first 80 PCIs and the rest allocated to the small cell layer.

We evaluate inter-layer assignment performance in terms of the six metrics given in table I that are derived from the objectives in Section II. One should note that the four metrics 'conf', 'mod30', 'm_0' and 'm_1', are subject to double counting, since each cell that observes the event adds it to the total count. The conclusions drawn from the result are however consistent, since the same behavior is applicable in all scenarios.

TABLE I
UDN PCI assignment evaluation metrics

Acronym	Description
NoPCIs	Number of cells which have not been assigned PCIs. This happens, when the PCIs are exhausted
PCIs	The number of PCI values used in the assignment
conf	The count of PCI confusions after the assignment
mod30	The count mod 30 conflicts after the assignment.
m_0	The count of m_0 conflicts
m_1	The count of m_1 conflicts

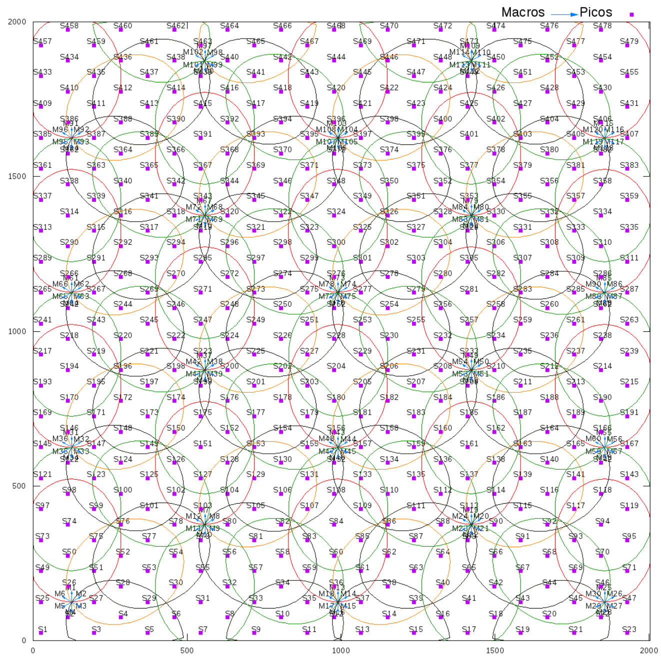

Fig. 9. Example UDN model: 6-sector macro sites with 500 m ISD and omni directional pico cells with 100 m ISD

The observed simulation results are shown in the multi-plot in Fig. 10. Each plot indicates the performance, in terms of the 6 metrics, for each of the different combinations of the strategies and safety margins. To highlight the benefit of the ANR-based learning, we show the performance of the blind assignment before learning the NRs (which we call blind assignment) as well the final performance of the full solution after the NRs have been learned (called blind SC layer).

The corresponding results are showed in Fig. 10, from which the following observations can be made:

1) Range separation performs poorly in all scenarios. At best, it avoids PCI confusions, when the SM is high, but still generates too many mod30, m_0 and m_1 conflicts. In principle this strategy is simply unusable even in low density scenarios.

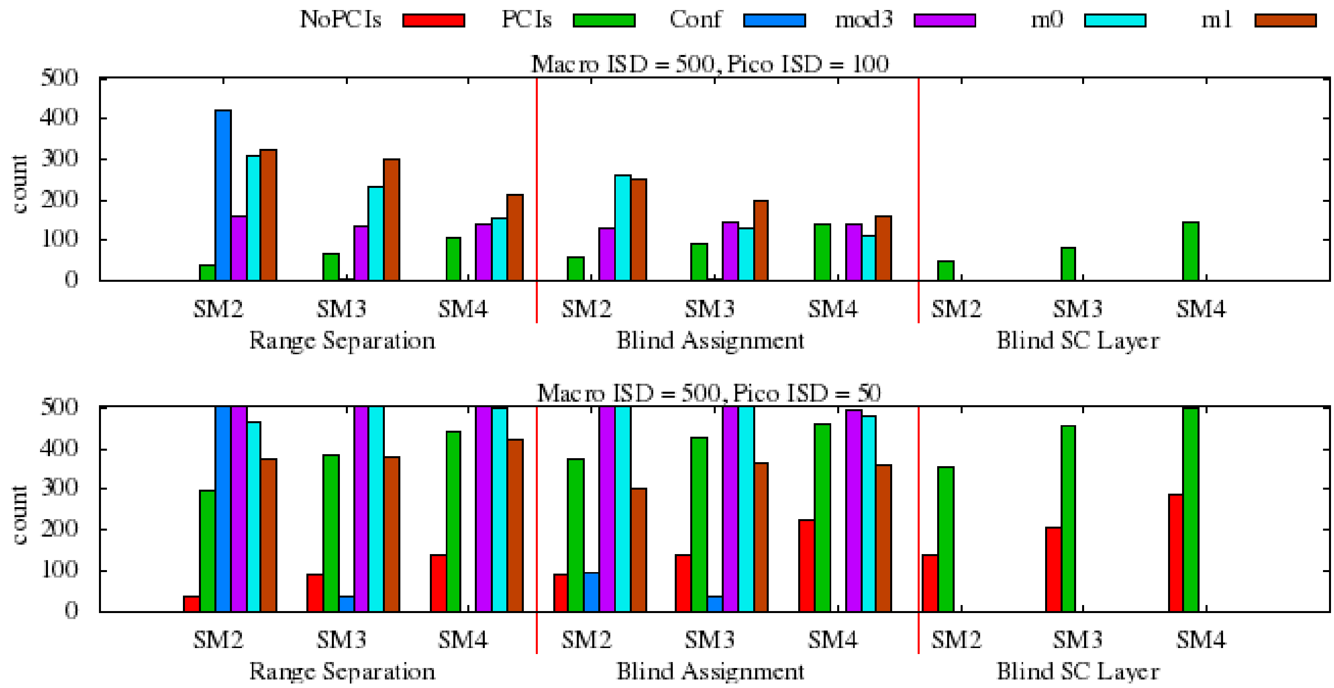

Fig. 10. PCI reuse and conflicts in four scenarios of varying pico cell densities.

2) Blind assignment significantly minimizes PCI confusions and even eliminates them in low density environments (see the 100 m pico-cell ISD case). It is however unable to reduce mod30, m_0 and m_1 conflicts, since that requires each cell to know the exact PCI assignments in its neighbor cells.
3) Learning the macro layer PCI assignments (in the Blind SC layer) eliminates mod30, m_0 and m_1 conflicts, since it allows each cell to consider the assignments in the neighbor cells. In minimizing these conflicts, however, it employs more PCIs than those used through the initial blind assignment. The result in very dense network scenarios, evident in the 50 m pico-cell ISD scenario, is that the PCI space is exhausted much earlier. E.g., there are more "No PCI" cases for the blind SC layer compared to the blind assignments in the 50 m pico-cell ISD scenario. Note that, the "No PCI" statistic is only an indication of how many violations will have to be allowed to exist. In practice, an operator could rather consider violating some of the mod and m_0/m_1 constraints (i.e. consider them soft) than not assigning any PCI at all, which extends the supported density.

It is evident from the results above that blind PCI configuration combined with ANR based learning of the PCIs previously assigned to neighbor cells achieves the desired compromise of enabling independent assignment in each layer, while minimizing the subsequent conflicts. The initial blind assignment of small cells PCIs already minimizes PCI confusions, but it is still unable to eliminate other conflicts, without requiring prior knowledge of the other layers. Then, ANR based learning provides full information of the macro layer PCI assignments, which is utilized by the small cell layer to optimize the initially blindly assigned PCIs, removing the remaining conflicts.

VII. Conclusions

As the current multi-layer networks evolve into Ultra-Dense Networks (UDNs) in future 4G and 5G deployments, new challenges arise one of which is the auto-configuration of Physical Cell Identities (PCIs), where the increased cell density complicates the PCI assignment in co-channel multi-layer UDN scenarios. Our earlier worked showed that using the split PCI range leads to high numbers of PCI conflicts in inter-layer neighbor relations [7]. Yet, assigning several layers from a single PCIs range requires either the use of same PCI assignment solution for all layers or communicating the network topology and the PCIs among them.

To avoid costly multi-vendor integrations based on a single PCI range or the need for meshed inter-layer exchanges (and the equivalent meshed X2 links), we have proposed a new strategy for PCI assignment that minimizes the need for sharing information among the layers while minimizing or removing the possible conflicts. First an initial blind small cell PCI assignment uses an educated initial estimate for sufficient PCI Safety Margin (SM) in the small cell layer. While this already outperforms the current range separation based solutions, our solution further adds new components that leverage Automatic Neighbor Relation (ANR) to learn macro layer PCIs. The initially assigned small cell PCIs are then optimized using the learned macro cells PCIs and normal graph coloring based approaches. Our evaluation shows that this solution is able to assign PCIs in each layer independently, but still avoid the conflicts that arise, when simple PCI range separation strategy is used.

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