# Neighbor Cell Relation List and Physical Cell Identity Self-Organization in LTE

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***Abstract*— Automation of radio network management is a key determinant to work reduction for wireless operators. By replacing time consuming and costly tasks with automatic mechanisms, operational expenditure can be reduced. In this paper we present a method for automatic configuration of locally-unique physical cell identities and neighbor cell relation lists in 3G Long Term Evolution (LTE). This method makes use of mobile measurements to update the neighbor cell relation lists in the cells and to detect local cell identity conflicts, report the conflicts to the Operation Support Systems (OSS) and resolve them. The performance of the approach is determined using simulations of realistically deployed macro networks. Conducted simulations illustrate the ability of the method to resolve local cell identity conflicts. In particular, the method is capable of both accommodating new cells and handling a worst case scenario where all cells are initiated with the same local cell identities and where neighbor cell relation lists are empty.**

***Keywords - Self-organization, Neighbor Cell Relation, Physical Cell Identity, Autonomic Communication, LTE, WCDMA.***

## I. INTRODUCTION

The need for even higher data rates, new services, and improved services has driven the standardization and development of the 3G Long Term Evolution (LTE). The LTE concept consists of an evolved radio access network (E-UTRAN), and an evolved packet core (EPC). The Third Generation Partnership Program (3GPP), has listed a set of requirements that the LTE concept should fulfill, including downlink and uplink peak data rates of 100 Mbits/s and 50 Mbits/s, respectively [1][2].

LTE is based on a rather flat architecture compared to 2G and 3G systems. Each cell is served by an eNodeB ("base station"), and handovers between cells are handled mainly by signaling directly between the eNodeBs, and not via any radio network controller node like in 2G and 3G. The cell broadcasts an identifying signature, a "fingerprint" (*Physical Cell Identity, PCI*), which the mobiles use to identify cells, and as time and frequency reference. These identifying signatures are not unique (there are 504 different PCIs in LTE). In addition, we propose to broadcast a globally unique cell identifier (GID), which can be detected and reported by the *user equipments* (mobiles). Detecting the GID will be more difficult and time consuming, which in turn implies restrictive use. Since handover is distributed to the eNodeB it benefits from a eNodeB managed neighbor cell relation (NCR) list of plausible handover candidates with connectivity information (e.g. IP address), as well as a mapping between the PCI and the globally unique cell identifier, GID. This enables the mobile to identify cells in measurement reports only by the PCI. Fig. 1 illustrates the concept of neighbors and cell identities. It also illustrates the O&M interface between the eNodeBs and the Operations Support System (OSS). For further reading about LTE we refer to [1].

In parallel with the LTE specification and development, the Next Generation Mobile Network (NGMN) association of operators brings forward requirements on management simplicity and cost efficiency. NGMN has summarized such requirements on Self-Organizing Networks (SON) in a number of operator use cases [3]. The vision is that centralized and decentralized algorithms automate tasks that currently require significant planning efforts. One use case considers handling of neighbor cell relations (NCR) lists, which is identified as a parameter that benefit from self-organization.

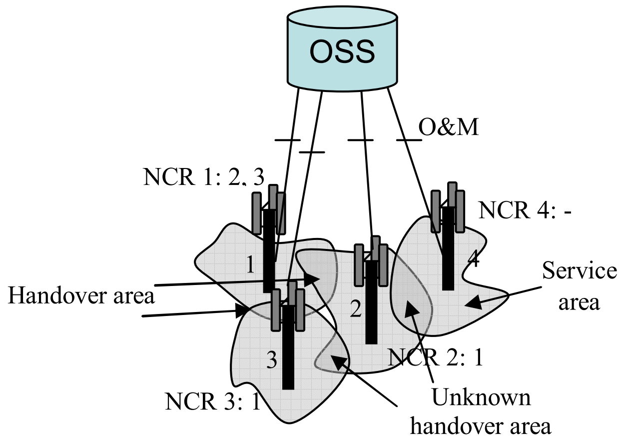


Figure 1. OSS monitors neighbor cell lists, and manages PCIs. Some cells have complete knowledge of theneighbor relationss (cell 1), some cells miss neighbor relations possibly due to inaccurate models in the planning step (cell 2 and 3) and some cells are newly installed without neighbor info (cell 4).

In 2G and 3G systems NCR lists have been populated using cell planning tools by means of coverage predictions before the installation of a base station. Prediction errors, due to imperfections in map and building data, have forced the operators to resort to drive/walk tests to completely exhaust the coverage region and identify all handover regions. This has proven to be costly and new methods for automatically deriving NCR lists are required. Furthermore, the LTE specification includes *closed subscriber group (CSG)* cells, also sometimes denoted Home eNodeBs, which a consumer may purchase and install in her/his home. This means that traditional drive/walk test becomes even more difficult.

The second issue in this paper is PCI management. Radio networks need to handle non-unique local physical identifiers of cells to support efficient measurement and reporting procedures. For example, in LTE a mobile is required to measure the *reference signal received power (RSRP)* (i.e. the received power of the signature sequence symbols associated with a particular PCI) of *candidate cells* and report to the *serving cell* (the cell serving the mobile at the moment). It is important to detect and resolve local PCI conflicts, i.e. when two cells in the vicinity of each other uses the same PCI, to avoid ambiguities in the measurement reports.

The contributions in this paper aid operators in decreasing their Operating Expenditures (OPEX) by moving NCR list and PCI management functionality from operators to the system itself. See further details in [13][17] and coming journal paper.

The remainder of this paper is organized as follows. In Section II we give an overview of related work. This is followed by Section III, where the approaches to the problems stated are described. The performance evaluation is presented in Section IV, followed by conclusions in Section V.

## II. RELATED WORK

PCI conflict resolution corresponds to code planning and resolution in WCDMA systems. One difference, however, is that no globally unique cell identity is reported by the mobiles in WCDMA. There are some papers appearing on code planning for WCDMA systems, e.g. [4][5], but there is no literature describing automatic PCI conflict resolution.

In 2G and 3G systems, the mobiles need NCR lists in order to report candidate cells, but in LTE the mobiles operate without NCR lists. Instead, it is the eNodeBs that benefit from the NCR lists. Considering NCR generation, one of early approaches was formulated for GSM, D-AMPS, and PDC in [6][7]. In their approach a set of new test cells (frequencies) are added to the neighbor list of a cell. This enables a mobile to measure cells currently not on the NCR list of the cell serving the mobile. The product implementation of the proposed method is briefly discussed in [8]. In contrast, we propose a method, which utilizes a feature of LTE, namely that the mobile detects a new cell and reports to the base station, making the detection of new cells easier.

In WCDMA, the mobiles are capable of detecting and reporting cells not listed in the neighbor cell list – detected set reporting (DSR) [2][9]. Soldani and Ore report results on self-optimization of NCR lists for UTRA FDD networks using DSR measurements [10]. This approach is not directly applicable to LTE, where it is possible for the mobile to extract the globally unique cell identifier and report to the eNodeB. Baliosian and Stadler developed a centralized procedure for creating NCR lists [11] where each base station intersects the set of mobiles in its service area with the mobiles in the service area of all other base stations. Parodi et al. [12] proposed a method for NCR definition, where the service area of the cells are approximated and their overlap is computed.

## III. APPROACH

With an extensive use of mobile-assisted measurements, which is already part of the handover procedure, automated updates of NCR lists and detection and resolution of PCI conflicts are made possible. For detection of situations where two cells with overlapping coverage use the same PCI an additional mechanism is needed. In the following sections, methods and procedures for NCR management, PCI conflict detection and PCI conflict resolution are described, giving an efficient and flexible alternative to drive testing and manual tuning. The proposed algorithm runs both in eNodeB (NCR management) and in the Operation Support System, OSS (PCI conflict resolution). Information will be centralized in the latter case, but the algorithm acts upon detected PCI conflicts and uses local information related to the conflicting cell, its neighbors and neighbors' neighbors. This means that the algorithm could be decentralized to the eNodeBs and be based on signaling between eNodeBs only as is described in [13].

The globally unique cell identifier (GID) in LTE consists of two parts:

- PLMN Identity: The identity of the Public Land Mobile Network. Note that a cell may have multiple PLMN identities.
- CIPL: Unique Cell Identity for a cell within a PLMN [14].

We will assume that whenever a new cell is introduced into the system it contacts a configuration server in the network. The configuration server provides the new cell with the GID identity and an IP address, and other initial parameter values. Optionally, the configuration server may also provide the cell with an initial PCI. One way of selecting the initial PCIs, which allows PCI grouping, could be $PCI_{\text{initial}} = CIPL \bmod A + B$ where $A$ is the PCI group size and $B$ is the first PCI in the corresponding PCI group. PCI grouping can e.g. be used to ensure that there are no conflicts between macro and micro cells.

### A. NCR Management and PCI Conflict Detection using Handover Measurements

The mobiles continuously measure the RSRP from the serving cell and candidate cells (cells in the vicinity of the mobile that might be considered as handover candidates). A measurement report is typically triggered when the RSRP from a candidate cell is within a threshold $D$ dB from the serving cell RSRP.

The measurement report contains information about the PCI and the corresponding RSRP of the candidate cell. The serving cell may order the mobile to read the GID (transmitted on the broadcast channel from each cell) of a cell with a certain PCI and report that back to the serving cell.

This could be done for example if the PCI is associated with a cell with handover failures in the past or if a central node such as the OSS has requested it. In any case, the GID of a neighboring cell can be obtained with help from a mobile station upon request from the serving cell. In case the serving cell decides to set up a relation to the neighboring cell it contacts the central configuration server in the network and obtains the IP address (and possibly other connectivity related information such as encryption and authentication keys).

When a measurement report is received from a mobile it is handled according to the following scheme:

Is the PCI of the candidate cell already known in the serving cell (i.e. is the neighbor relation already established)?

**Yes**: Initiate handover decision procedure.

**No**: Consider the candidate cell as a NCR list candidate. Order the UE to report GID. Obtain connectivity information for the candidate cell and signal to the candidate cell, directly or through the core network, about a mutual addition to the NCR lists of the two cells. Does the candidate cell confirm the NCR list addition?

> **Yes**: Add the candidate cell to the NCR list, and store relevant information about the cell. Initiate a handover decision procedure.
>
> **No**: The candidate cell has detected a PCI conflict in the NCR list addition procedure. The candidate cell informs OSS about the PCI. Handover may be initiated simultaneously through the core network, using the GID as identifier.

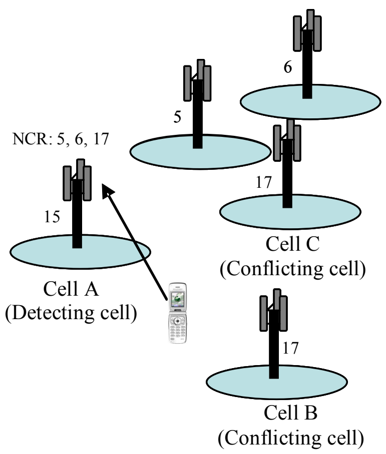


Figure 2. PCI conflict detection based on handover measurements. The mobile reports a new candidate cell with a PCI already present in the NCR list of the serving cell.

Two ways of detecting PCI conflicts by using handover measurements are illustrated in Fig. 2, where cells B and C are in conflict. Either, cell A is the serving cell, the mobile approaches cell B and reports it as a candidate cell, and cell A detects the PCI conflict. Alternatively, cell B is the serving cell and the mobile approaches cell A. The mobile then reports cell A as a candidate cell, and cell B adds cell A to its NCR list. However, when enforcing a mutual neighbor relation, cell A once again detects the PCI conflict. When a PCI conflict is detected it is reported to OSS, in both these cases by cell A.

OSS may initiate a network wide re-planning of PCIs when a conflict is detected. However, the proposal in this paper is to perform a local adjustment that only involves the PCI update of one of the conflicting cells based on local information from the conflicting cell, its neighbors and their neighbors. First, OSS determines which of the conflicting cells that should change PCI. It could be at random, or for example be the conflicting cell i) with the *lowest GID*, ii) with the *shortest NCR* list or iii) that most *recently changed PCI* that will change the PCI. Only little differences are reported in [13]. In the following sections, the cell chosen to change its PCI is referred to as the *selected conflicting cell*. The subsequent resolution can be divided into four steps:

A. Compilation of a set of locally conflicting PCIs by retrieving the PCIs of the neighbors and neighbors-neighbors to the selected conflicting cell.

B. Determination of the locally non-conflicting PCIs as all available except the locally conflicting PCIs.

C. Randomization of a new PCI from the locally non-conflicting PCIs.

D. Information about the PCI update to all cells with NCR lists containing the selected conflicting cell

### *B. PCI Detection and Resolution using Transmission Gaps*

Another type of PCI conflict is when the candidate cell has the same PCI as the serving cell. For example, if the mobile is served by cell C in Fig. 2, and approaches cell B. In that case, the mobile may not be able to report the weaker cell to the serving cell because the weaker cell is directly interfered by the serving cell on the same signature sequence. This comes about because the mobile cannot differentiate between normal multi-path in the radio channel and the case when the same signature sequence is transmitted from two different cells. If the two conflicting cells have at least one neighbor candidate cell in the vicinity that can detect the conflict, the conflict will eventually be solved by that cell.

If no such neighbor candidate cells exist or in order to increase the conflict detection opportunities, the serving cell could issue a transmission gap at predefined times. During each such transmission gap the mobile would search for the signature sequence associated with the serving cell. If the mobile detects this sequence during a gap it knows that the signature sequence is transmitted by another cell in the system (i.e. not the serving cell) and it can inform the serving cell about the PCI conflict. The start time of the transmission gaps should be randomized. In order to reduce the risk for overlapping transmissions gaps between different cells the GID could be used as a seed in the randomization. The serving cell can indicate the PCI conflict to OSS, which initiate a PCI update with the indicating cell as the selected conflicting cell. Note that OSS does not need to determine the other conflicting cell.

## IV. PERFORMANCE EVALUATION

In order to illustrate and analyze the behavior of the proposed NCR list and PCI management, we consider simulations using two scenarios with realistically deployed networks. The goal of the performance evaluation is to see whether existing PCI conflicts are resolved and NCR lists reach a steady-state. Section IV.A describes the two scenarios in more detail, and Section IV.B provides information about the simulation environment. The subsequent sections present and discuss the simulation results.

### A. Scenarios

#### 1) Mjärdevi Scenario

The first scenario is selected for illustrative purposes. It is a fictitious network in Mjärdevi (Linköping, Sweden), see Fig. 3. A supposedly good and adequate macro deployment with 30 cells is evolved with the addition of five micro cells to better cover areas between houses. These micro cells initially have empty NCR lists, are not listed in any neighbor cell lists of the macro cells, and are initiated with conflicting PCIs. This is to mimic the situation that may arise when no effort whatsoever is made to configure the introduced micro cells. The radio propagation is based on the Okumura-Hata model (see e.g., [16]) adapted for 3G as the propagation model. Further, the building loss model used is given by -24-1.6*d* dB, where *d* is the distance to the closest outer wall. The house canyon (in-between buildings) loss is -12-0.8d dB, where *d* is the distance to the closest inner wall. The micro cell propagation model is -50-0.8*d* dB, where *d* is distance from the micro cell in meters.

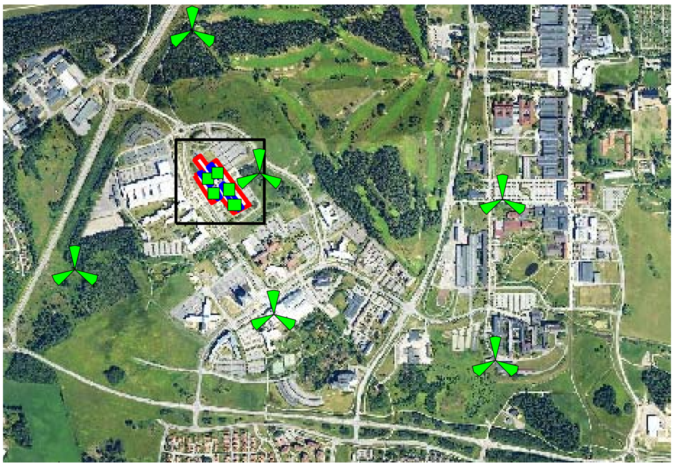

Figure 3. Aerial view of the fictitious deployment in Mjärdevi Linköping. The outer walls of the building are marked with grey (red) lines. The inner walls (facing the in-between building area) are marked with dark (blue) lines.

Furthermore, the total number of available PCIs has been reduced from the normally available 504 to only 30, in order to make the problem more challenging.

#### 2) Major City Scenario

The second scenario is a part of a realistic network in a major Western European city. The considered area has more than 200 cells. As in Section IV.A.1) we use TEMS CellPlanner together with Okumura-Hata to predict the radio propagation. The details are omitted due to space limitations. This network is much denser than the first scenario, which means that there are many more inter-dependencies between the cells. The network is initiated with empty neighbor cell lists and all cells initially have the same PCI, in order to provide a worst case situation. In addition, we consider two cases where the number of available PCIs is either 130 or 504 in order compare how such restriction has an impact on the performance, as well as to provide means to make the problem more challenging.

### B. Simulator

The simulator essentially generates mobiles in the network scenarios according to given traffic distributions, and extracts the mobiles that are in positions where they would trigger and send handover measurements of the RSRP. The NCR list and PCI management algorithm is then implemented to act upon the handover measurements from the mobiles, to add NCR list entries, and to detect and resolve PCI conflicts. Unless otherwise stated, the lowest GID strategy is adopted when selecting which of the conflicting cell that is requested to change its PCI. We will in Section IV.D investigate the other strategies as outlined in Section III.

### C. Simulation Results from the Mjärdevi Scenario

Coverage data from all possible positions in the network are used to compile the ideal NCR list. It is concluded that in total 28 neighbor cell list entries needs to be added when introducing the micro cells. Recall that the micro cells do not have any entries in the neighbor cells lists initially, and they are not listed in any of the macro cells either. The result is given in Fig. 4, which shows that the algorithm is able to find all necessary 28 entries in the neighbor cell lists. Accumulated NCR updates triggered by PCI changes, as shown in Fig. 5, can be seen as indicators of the PCI conflict resolution performance and convergence. Comparing to Fig. 4, we see that the PCI conflict handling converges faster than the NCR additions. In summary we have shown that the PCI and NCR handling approach presented in this paper automatically updates the NCR lists as handover information becomes available. Further PCI conflicts are resolved and the network reaches steady state.

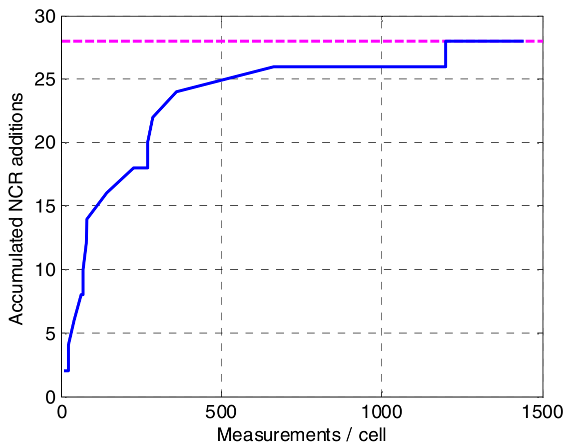


Figure 4. Neighbor cell list convergence. Accurate NCR lists are achieved after approximately 1000 measurements per cell made by mobiles in handover situations.

### D. Simulation Results from the Major City Scenario

Fig. 6 illustrates the convergence of the PCI conflict resolution algorithm and indicates that it is able to gradually resolve the PCI conflicts and provide locally conflict free PCIs to the cells. Note that in Fig. 6 we have made the problem more challenging by decreasing the total number of available PCIs to 130. Even so, the accumulated collisions (conflicts) converge to steady state after approximately the same time as the case when 504 PCIs are available. It can be noted that much fewer measurement reports per cell are needed for the algorithm to converge in this scenario compared to the simpler and smaller Mjärdevi scenario (see Section IV.C). The reason is that the inter-dependencies in this relatively dense network provide more informative measurements and updated PCIs spread to more neighboring cells quicker due to the longer lists.

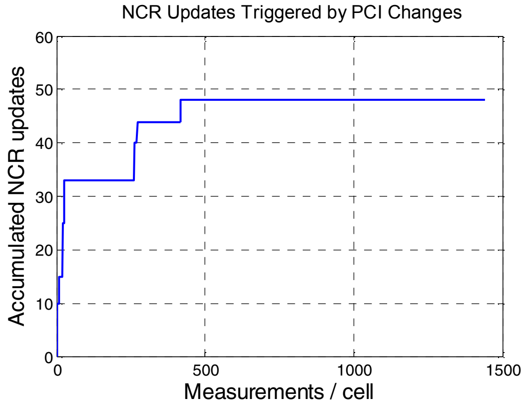


Figure 5. Accumulated number of NCR updates as an indicator of PCI conflict handling performance and convergence.

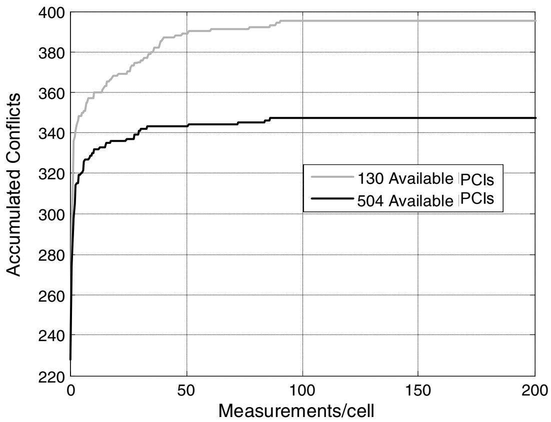


Figure 6. The maximum number of PCI is set to 130 and 504, respectively. All cells were initiated with identical PCI.

We observe that the results of the major city scenario are in line with the Mjärdevi case, i.e., we have shown that the PCI conflicts are resolved and that the network reaches an equilibrium state where no further conflicts are detected. The approach is to some extent insensitive to the number of PCI's available and, as such, the PCI management algorithm ensures locally unique PCI's even if the total number of PCI's is significantly lower than the current specification (as specified by 3GPP). This is an important aspect since denser networks are expected as the deployments evolve and with the inclusion of micro cells, pico cells and Home eNodeBs.

## V. Conclusion

We have developed and proposed a set of algorithms for automating the operation of the 3G Evolution radio network LTE. These algorithms aim at solving PCI conflicts and generating and updating NCR lists using mobile-assisted measurements. The algorithms are fully automated and run continuously, thus, they require no operator intervention. The performance evaluation shows that the network converges to a steady state, where there are no PCI conflicts and the NCR is complete. Having developed and successfully shown the performance of this approach, we believe that the results will have a significant positive impact on the operator OPEX.

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