Neighbor Cell Relation List and Measured Cell Identity Management in LTE

Mehdi Amirijoo, Pål Frenger, Fredrik Gunnarsson, Harald Kallin, Johan Moe, Kristina Zetterberg
{mehdi.amirijoo, pal.frenger, fredrik.gunnarsson, harald.kallin, johan.moe, kristina.zetterberg}@ericsson.com

Abstract—Radio network management simplification concerns to some extent the removal, not the simplification, of tasks. In this paper we present an approach for automatic network management in 3G Long Term Evolution (LTE), namely, methods for automatic configuration of locally-unique physical cell identities and neighbor cell relation lists. We show that these issues can be removed from the list of planning tasks and completely replaced by autonomous algorithms. These algorithms make use of mobile measurements to detect local cell identity conflicts, resolve them, and to update the neighbor cell relation lists in the cells. The performance of the approach is determined using simulations of realistically deployed macro networks. The simulations illustrate the ability of the algorithms to resolve local cell identity conflicts. In particular, the algorithms are 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. The contributions in this paper are meant to aid operators by allowing them to replace time consuming and costly tasks with automatic mechanisms, thus, reducing operational expenditure.

Index Terms - Self-organization, Neighbor Cell Relation, Measurement Cell Identity, Autonomic Communication, LTE, WCDMA.

I. INTRODUCTION

The emergence of 3G networks has enabled high capacity communication for mobile consumers around the world. In 2006 the number of users around the world accessing 3G networks passed 2 billion and the number of new subscribers is still rising [1]. 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 requirement that the LTE concept should fulfill, including downlink and uplink peak data rates of 100 Mbits/s and 50 Mbits/s, respectively [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” (Measured Cell Identity, MCI), which the mobiles use to identify cells, and as time and frequency reference. These identifying signatures are not unique (there are 504 different MCIs 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 managing a neighbor cell relation (NCR) list of plausible handover candidates with connectivity information (e.g. IP address), as well as a mapping between the MCI and the globally unique cell identifier, GID. This enables the mobile to identify cells in measurement reports only by the MCI. Fig. 1 illustrates the concept of neighbors and cell identities. 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. Cell 1 has a complete knowledge of its neighbors. Cell 2 only knows about Cell 1 and not Cell 3. This may be due to prediction errors as a result of inaccuracies in the signal propagation model and map data used in a manual planning step. Cell 4 is newly installed and is thus not aware of – or by – any neighbors.

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. Since a radio network gradually evolves over time with new cells and changing interference circumstances, centralized planning of MCI and NCR lists requires iterative repetitions of the planning procedure. This has proven to be costly and new methods for automatically deriving NCR lists are required. The situation is further complicated by the usage of many micro-cells and pico-cells covering small areas. This facilitates the deployment of new nodes in response to poor coverage or changes in traffic patterns. 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, since the operator no longer has control of the actual locations of all base stations. Thus, it is essential to make use of automatic in-service approaches for generating and updating NCR lists.

The second issue in this paper is MCI 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 symbol received power (RSRP) (i.e. the received power of the signature sequence associated with a particular MCI) of candidate cells and report to the serving cell (the cell serving the mobile at the moment). This is to ensure efficient and timely handover (HO) to another cell if needed. If all MCIs are unique within the vicinity of the serving cell, there will be no ambiguities in the measurement reports.

There are two possible cases that may cause conflicts. First, two different cells in the same NCR list have the same MCI. Second, two overlapping cells have the same MCI. MCI conflicts may arise when a new base station is deployed (assuming the base station chooses an MCI arbitrarily, or at least without planning efforts) or new neighboring cells are detected, which results in updates to the NCR list. The problem that we address is how to solve MCI conflicts automatically without the intervention of an operator, which previously was needed.

While self-organization has been used and developed in other fields of technology, e.g., autonomic computing [4], telecommunication networks have still not fully exploited the true potentials of self-organization. In this paper we contribute by presenting an automatic and decentralized approach for

- generating and updating NCR lists and
- resolving MCI conflicts.

These contributions aid operators in decreasing their Operating Expenditures (OPEX) by moving NCR list and MCI management functionality from the operators to the system itself.

The remaining 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

For an overview on autonomic communication refer to [5][6]. MCI 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. [7][8], but there is no literature describing automatic MCI conflict resolution. Further, previous papers [7][8] present techniques for choosing scrambling codes such that, e.g., the synchronization error probability and processing power requirements of the mobile are minimized, which does not apply to LTE since hierarchical codes are not used in LTE.

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 [9][10]. 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. Statistics on signal quality (as measured by the mobiles), HO, and drop call rate are used as input to the algorithm. The product implementation of the proposed method is briefly discussed in [11]. 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. Furthermore, the papers do not discuss conflicts in non-unique cell identities (MCI in this paper).

In WCDMA, the mobiles are capable of detecting and reporting cells not listed in the neighbor cell list – detected set reporting (DSR) [2][12]. Soldani and Ore report results on self-optimization of NCR lists for UTRA FDD networks using DSR measurements [13]. The suitability of newly detected neighbors is evaluated using an aggregated performance metric, which includes indicators such as HO success ratio, HO share, and $E_{UO}$. The neighbors are ranked and the best cells are chosen for deployment in the updated NCR list. This approach is not directly applicable to LTE, where instead the correspondence to detected set measurements is used in the handover procedure, and that it is possible for the mobile to extract the globally unique cell identifier and report to the eNodeB.

Baliosian and Sadler developed a procedure for creating NCR lists [14]. Each base station intercepts the set of mobiles in its service area with the mobiles in the service area of all other base stations. Neighbor relations are formed if the size of the intersected set is larger than a given threshold $H$. This algorithm must be executed periodically causing a traffic overhead in the network. Appropriate values for the period of the algorithm and the parameter $H$ must be derived. The latter adds to the list of parameter that need to be set by an operator or developer.

Parodi et al. [15] proposed a method for NCR definition, where the service area of the cells are approximated and their overlap is computed. Two cells are neighbors if their
approximated service areas overlap. Antenna and wave propagation models are used to estimate the service areas. The accuracy of the models used highly affects the validity of the generated NCR lists and, as such, generated NCR lists may be erroneous since antenna and propagation models may be inaccurate due to, e.g., unknown terrain data. In contrast to [14] and [15], we have taken an approach relying on mobiles to monitor and report neighbors. This eliminates the need of antenna and propagations models and provides accurate information provided by the mobiles. Further, a method for resolving MCI conflicts is proposed.

In mobile ad-hoc networks (MANETs) two or more nodes may have the same MAC address [16]. This causes conflicts resulting in neighboring nodes to erroneously pick up each other’s frames. The MAC address needs therefore to be locally unique in order to ensure correct delivery of the packets. The authors suggest a solution where a unique identifier (GID in this paper) is included in the intended node’s frame, which is then broadcasted. A receiving node then checks to see whether the unique identifier matches its own. If this is the case, then the frame is accepted, otherwise it is discarded. The same concept may be applied to LTE. However, this requires additional bits to be transmitted over the radio link, which is a rather inefficient procedure and a more elaborate approach is required.

### III. APPROACH

As mentioned earlier, radio networks of today evolve over time which results in a need for automated management of NCRs and MCIs. 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 MCI conflicts are made possible. For detection of situations where two cells with overlapping coverage use the same MCI an additional mechanism is needed. In the following sections, methods and procedures for NCR management, MCI conflict detection and MCI conflict resolution are described, giving an efficient and flexible alternative to centralized planning. It is described as a distributed algorithm that executes in eNodeB, but it could also be implemented in a centralized operation and management node. In addition to the already introduced concepts NCR and MCI the following notation will also be used in the forthcoming sections:

- 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 [17].

In combination, PLMN and CIPL yield the globally unique cell identifier (GID). 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 MCI. In order to minimize MCI conflicts and to allow for MCI grouping the initial MCI may be selected as $MCI_{initial} = CIPL \mod A + B$ where $A$ is the MCI group size and $B$ is the first MCI in the corresponding MCI group. MCI grouping can e.g. be used to ensure that there are no conflicts between macro and micro cells.

#### A. NCR Management and MCI 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 may contain information about more than one handover candidate in the mobiles’ surroundings.

The measurement report contains information about the MCI 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 MCI and report that back to the serving cell.

This could be done for example if the MCI is associated with a cell with handover failures in the past or if a central node such as the Operation Support System (OSS) has requested it. Another approach would be to query GID every time before a handover is made; this however leads to an increased amount of signaling, possibly slowing down the handover process. 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 new measurement report and a subsequent GID report are received from a mobile it is handled according to the following schematic algorithm:

1. **Yes**: Does the GID of the candidate cell match the GID of the existing neighbor with the same MCI?
   - Yes: Initiate handover decision procedure.
   - No: Resolve the MCI conflict.

2. **No**: Consider the candidate cell as a NCR list candidate. 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 an MCI conflict in the NCR list addition procedure. The candidate cell resolves the MCI conflict and confirms the NCR list addition once the MCI conflict is resolved. Handover may be initiated simultaneously through the core network, using the GID as identifier.
The two types of MCI conflicts that can be detected through handover measurements are illustrated in Fig. 2 and Fig. 3, where detecting cell and conflicting cells are defined. When an MCI conflict is detected an MCI conflict resolution procedure is started. The procedure is illustrated in Fig. 4. The cell detecting an MCI conflict decides which of the conflicting cells that should change MCI. The decision is based on one of the following criteria:

1. The conflicting cell with the lowest GID will change the MCI.
2. The conflicting cell with the shortest NCR list will change the MCI.
3. The conflicting cell that most recently changed MCI will change the MCI.

A comparison between the three different criteria is made in Section IV. In the following sections, the cell chosen to change its MCI is referred to as the selected conflicting cell. The cell not selected is referred to as the non-selected conflicting cell. The subsequent resolution procedure is illustrated by Fig. 4 and can be divided into four steps:

A. The detecting cell orders the selected conflicting cell to change its MCI.

B. The selected conflicting cell gathers list of conflicting MCIs from its neighbors to determine the set of locally conflicting MCIs. The selected conflicting cell now knows all the MCIs that are already occupied among its neighbors and neighbors’ neighbors.

C. The selected cell randomizes a new MCI from the non-conflicting MCIs.

D. The selected conflicting cell informs its neighbors about the MCI change, and when the change will become effective.

The selected conflicting cell may reject the MCI change request, if an MCI change has already been initiated by another detecting cell.

B. MCI Detection and Resolution using Transmission Gaps

Another type of MCI conflict is when the candidate cell has the same MCI as the serving cell, see Fig. 5. 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. To intuitively explain why
this is the case we may consider two different scenarios. In the first scenario only the serving cell is transmitting a signature sequence. The mobile searches for this signature sequence by cross-correlating the received signal with the same signature sequence. In case the received signal contains the corresponding signature sequence then the cross correlation output will contain a distinct peak. The location of the peak provides the mobile with time synchronization and the amplitude of the peak is proportional to the signal strength of the corresponding cell. But due to multi-path propagation in the radio channel the mobile will receive multiple copies of the transmitted signature sequence that have different delay, amplitude and phase shift. There may e.g. be a direct signal path from the transmitter in the mobile and an indirect reflected signal path that arrives at the mobile a bit later. In this case the cross correlation operation in the mobile will result in two distinct peaks, one per radio path. The mobile uses this information to perform channel estimation and equalization. Now consider the case without multi-path but with two different cells transmitting the same signature sequence. The transmitted signals from the two cells will arrive at the mobile with slightly different delays, amplitudes, and phase shifts. The mobile performs a cross correlation with the received signal and the output will contain two distinct peaks, but in this case one peak per cell. The conclusion from this discussion is that the mobile can not 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 MCI 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 is both a detecting cell and one of the conflicting cells. It changes its own MCI, which simplifies things since the mobile does not need to detect the globally unique cell identity from the other conflicting cell. This reduces needed signaling.

C. In Operation MCI Reconfigurations

The procedure of changing MCI in real-time is important. Ongoing connections need to be maintained, which requires dedicated handling (e.g. the downlink synchronization is based on physical procedures in which the MCI plays an important role as the index of the code to correlate to and track). With such procedures in place, it can be assumed that the actual switching from one MCI to another in real-time is not a practical problem that prevents the adoption of the distributed MCI management.

In summary the actual MCI change is performed as follows (see Fig. 6):

1. The changing cell sends out an MCI change notification message (over the air) to served mobiles containing the old MCI, the new MCI, and a future time reference indicating when the MCI change will occur. At the time of the MCI change the mobiles switch from using the old reference symbols to the new reference symbols corresponding to the old and new MCI respectively.

2. The changing cell sends an MCI change notification message (over the network) to its neighbors so that they can update their NCR lists with the new MCI.

3. The neighboring cells may forward the MCI change notification message (over the air) to their respective cells. At the time of the MCI switch the mobiles switches from to performing handover measurements from the old to the new reference symbols corresponding to the old and new MCI respectively.

The MCI reconfiguration needs to be signaled to all cells in the NCR list of the selected conflicting cell to ensure that the NCR lists in those cells reflect the new MCI. Moreover, mobiles in the other cells may monitor and measure the selected conflicting cell as a handover candidate. To avoid disrupting the measurement and filtering procedures, also those
mobiles need to be informed about the MCI reconfiguration. This might be considered as a minor issue, but the serving cell signaling to served mobiles described above applies also for this purpose.

IV. PERFORMANCE EVALUATION

In order to illustrate and analyze the behavior of the proposed distributed NCR list and MCI management, we consider simulations using two scenarios with realistically deployed networks. The goal of the performance evaluation is to see whether existing MCI 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. 7. A supposedly good and adequate macro deployment with 30 cells (Fig. 8) is evolved with the addition of five micro cells to better cover areas between houses (Fig. 9). 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 MCIs. This is to mimic the situation that may arise when no effort whatsoever is made to configure the introduced micro cells. The radio propagation shown in Fig. 8 and Fig. 9 is predicted using the TEMS CellPlanner [18]. Using digital map data and a calibrated propagation model, TEMS CellPlanner can be used to accurately predict radio wave propagation for the topology in the proposed service area. We use the Okumura-Hata model (see e.g., [19]) adapted for 3G as the propagation model. Further, the building loss model used is given by \(-24-1.6d\) 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 \(-50-0.8d\) dB, where \(d\) is distance from the micro cell in meters.

Furthermore, the total number of available MCIs has been reduced from the normally available 504 to only 30, in order to make the problem more challenging. The latter implies that there will be more conflicts compared to the case where the total number of MCIs is 504.

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. The network is initiated with empty neighbor cell lists and all cells initially have the same MCI, in order to provide a worst case situation. In addition, we consider two cases where the number of available MCIs 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.
the mobiles that are in positions where they would trigger and send handover measurements of the RSRP. The distributed NCR list and MCI management algorithm is then implemented to act upon the handover measurements from the mobiles, to add NCR list entries, and to detect and resolve MCI conflicts. Unless otherwise stated, the lowest GID strategy is adopted when selecting which of the conflicting cell that is requested to change its MCI. We will in Section IV.D investigate the other strategies as outlined in Section III.

C. Simulation Results from the Mjärdevi Scenario

We shall start with considering 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. 10, which shows that the algorithm is able to find all necessary 28 entries in the neighbor cell lists. Accumulated NCR updates triggered by MCI changes, as shown in Fig. 11, can be seen as indicators of the MCI conflict resolution performance and convergence. Clearly, MCI conflicts happen less often as the algorithm progresses, and comparing to Fig. 10, we see that the MCI conflict handling converges faster than the NCR additions. In summary we have shown that the MCI and NCR handling approach presented in this paper automatically updates the NCR lists as handover information becomes available. Further MCI conflicts are resolved and the network reaches steady state.

D. Simulation Results from the Major City Scenario

Let us now consider the Major City scenario. Due to the sheer size of the network, the ideal NCR lists are not compiled in a planning tool. Instead, the algorithm is initiated with identical MCIs and without entries in the NCR lists. The objective is to investigate convergence from this worst case initial state. This network is much denser than the first scenario, which means that there are many more inter-dependencies between the cells.

Fig. 12 illustrates the convergence of the MCI conflict resolution algorithm and indicates that it is able to gradually resolve the MCI conflicts and provide locally conflict free MCIs to the cells. Note that in Fig. 12 we have made the problem more challenging by decreasing the total number of available MCIs to 130. Even so, the accumulated collisions (conflicts) converge to steady state after approximately the same time as the case when 504 MCIs 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 MCIs spread to more neighboring cells quicker due to the longer lists. In order to compare the selection strategies described in Section III.A, the major city scenario is initiated with the neighbor cell relation lists and MCIs that were obtained after the algorithm has converged. Then one cell is selected at random, its NCR list is emptied, and its entries in NCR lists of other cells are removed. Its MCI is set to be the same as one random cell in its prior NCR list in order to enforce a conflict.
Then measurements are generated upon which the algorithm operates, and the accumulated MCI collisions are recorded. This procedure is repeated 50 times, and the average convergence over the 50 different initial states is presented in Fig. 13. It can be concluded that the three strategies perform roughly equal, and that the differences are minor, especially when considering how many collisions in total that the strategies causes. The strategy, which selects the cell which most recently has changed MCI, results in a slightly better convergence rate. However, note that we are also interested in the strategy that requires the least signaling effort. A good choice is to use the lowest GID criterion since the GID is already known by the detecting cell.

We observe that the results of the major city scenario are in line with the Mjärdevi case; i.e., we have shown that the MCI conflicts are resolved and that the network reaches an equilibrium state where no further conflicts are detected. The approach is insensitive to the number of MCI’s available and, as such, the MCI management algorithm ensures locally unique MCI’s even if the total number of MCI’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. Further, we have shown that there is no major difference, in terms of number of generated MCI conflicts, when employing a particular strategy for selecting which cell to change its MCI.

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 MCI 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 MCI 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.

In our future work we intend to develop additional techniques for improving the performance of wireless access networks. These include automatic optimization of radio parameters, such as cell power and HO-related parameters.

REFERENCES

[17] 3GPP TS 36.300 v8.0.0, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN); Overall description; Stage 2”