Evaluations of LTE Automatic Neighbor Relations

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Abstract— **In recent years, there has been a strong focus on network management simplicity under the device self-organizing networks (SON). A number of SON use cases and features have been and are discussed for 3G Long Term Evolution (LTE). The main SON feature in the first LTE release is methods for automatic configuration of neighbor cell relations – Automatic Neighbor Relations (ANR). In this paper, we describe the neighbor relations management and ANR, and evaluate ANR in a pre-launch, commercially deployed network cluster. The results indicate that ANR configures discovered and needed neighbor relations such that handover can be performed in combination with the neighbor relation establishment without dropping the connection.**

Keywords- Self-organizing networks, Automatic Neighbor Relations, Physical Cell Identity LTE, WCDMA, SON, ANR, OSS.

I. INTRODUCTION

The need for even higher data rates, as well as new and improved services while being mobile have been drivers for the standardization work of the 3G Long Term Evolution [1][2]. The LTE concept consists of an evolved radio access network (E-UTRAN), and an evolved packet core (EPC). It has also been a strong momentum for requirements on management simplicity and cost efficiency of the new system, not the least from the Next Generation Mobile Network (NGMN) association of operators. They have summarized such requirements on Self-Organizing Networks (SON) in a number of operator use cases [3]. This is one of the reasons why SON has been on the agenda in 3GPP already from the first release of the specifications. 3GPP specifies the operation of a number of SON use cases, and the first one to become well-defined is automation of neighbor relation tables. The concept of neighbors and neighbor cells is further illustrated by Figure 1.

LTE is based on a rather flat architecture compared to 2G and 3G systems, see Figure 2. Each cell is served by an eNodeB or eNB ("base station"), and handovers between cells can be handled either via the Mobility Management Entity (MME) and the S1 interface, or directly between the eNBs via the X2 interface. The cell broadcasts an identifying signature or waveform, which can be seen as a "fingerprint", that the mobiles use both as time and frequency reference, as well as to identify cells. Each waveform is enumerated by the *Physical Cell Identity (PCI*). These identifying signatures are not unique (there are 504 different PCIs in LTE), and can therefore not be used to uniquely identify a neighbor cell In addition, each cell broadcasts as part of the system information a globally unique cell identifier (CGI). This is also the case in some prior systems, but LTE features the UE ANR (User Equipment Automatic Neighbor Relations) function, which means that mobiles shall decode and report the CGI information of neighbor cells to the serving cell upon request.

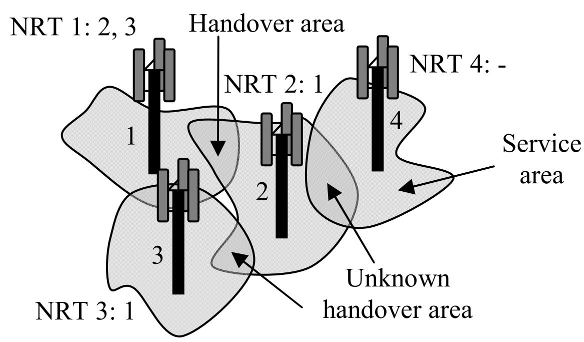

Figure 1. The base station maintains a neighbor relation table (NRT) for each cell. Roughly, each entry contains everything the base station needs to know about a neighbor. Cell 1 has a complete knowledge of its neighbors. Cell 2 only knows about Cell 1 and not Cell 3. This may be due to prediction errors 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, NRTs 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 PCI and NRT requires iterative repetitions of the planning procedure. This has proven to be costly and new methods for automatically deriving NRT lists are required.

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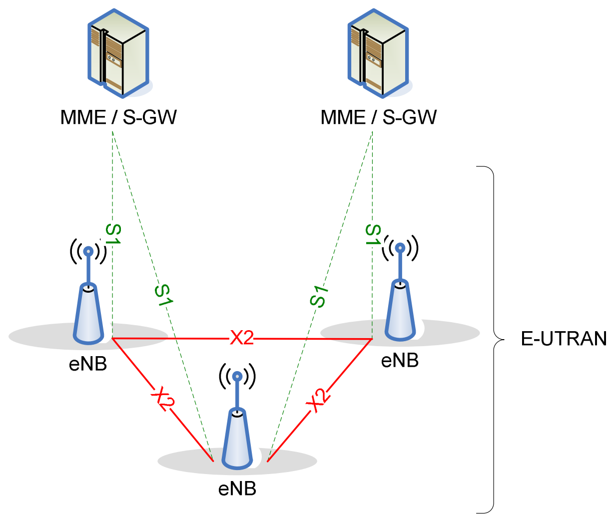

Figure 2. 3GPP LTE architecture.

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 NRTs.

In the remainder of the paper, we describe the 3GPP ANR function in more detail in Section II, and some related academic work in Section III. Section IV addresses both some measurement and reporting durations, illustrated by brief field evaluations the live ANR evaluations in a pre-launch commercial network. Finally, Section VI provides some conclusive remarks.

II. The 3GPP ANR Function

The ANR function in 3GPP is described in [2] and is illustrated by Fig.3. We will discuss NRT management and RRC signaling in more detail in the following subsections.

A. NRT Management

Traditionally, the NRT is defined from the operations and maintenance (O&M) system, and this possibility still exists even when ANR is implemented. However, it is possible to launch base stations without any NRT entries at all. Each NRT entry is uniquely identified by a target cell identifier. If the target cell is an LTE cell at the same frequency, this identifier is the CGI, and NRT also contains the PCI. It is the CGI that the eNB uses when signaling to another eNB via the MME, since the MME routes the messages based on eNB identity which is a part of CGI. The CGI is also used when acquiring via MME the IP address of another eNB, which is used for X2 interface establishment. Additionally, the NRT entry contains information about X2 availability, whether

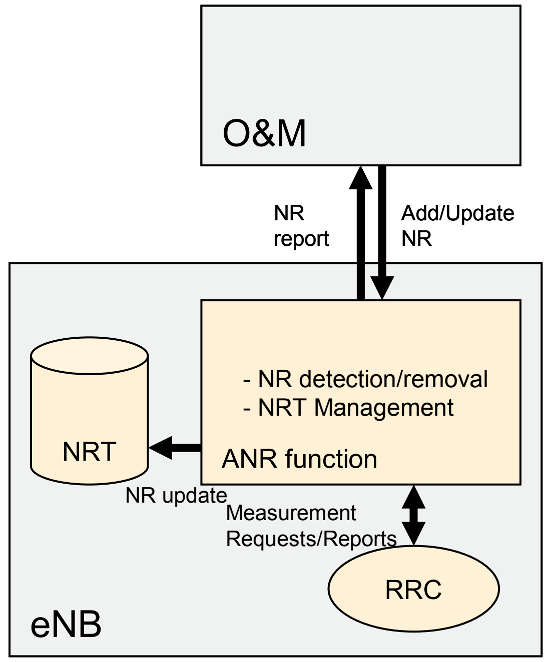

Figure 3. The 3GPP ANR Function.

ANR may remove the neighbor relation or not, and whether the neighbor relation may be used for handover or not.

At large, the main ANR function objectives are to automatically add and remove entries to/from NRT. NRT additions are driven by Radio Resource Control (RRC) signaling between the eNB and mobiles, which provides measurement control and reporting means. RRC is used to define measurements of candidate cells, which means that the mobiles reports measurement information to the serving base station, and upon request the mobile also decode and reports the unique CGI information.

If the policy is to establish X2 for neighbor relations and if X2 is not already available, then CGI is used to recover the target eNB IP address, which is used for X2 setup. When the X2 interface is established, the eNBs can share information about their served cells including PCIs and CGIs. Finally, the remaining NRT entry attributes are defined, either via O&M, or by using default values.

NRT entry removal is typically via timers, restarted every time a neighbor relation is used for handover. The entry is removed if the neighbor relation has not been used within a pre-determined time period.

B. RRC Signaling

Two different RRC signaling sequences are discussed in this section – handover when the neighbor relation is established and when not.

The RRC measurement control and report mechanisms can be seen as a toolbox. For further details, see [4]. Typically, the mobile is requested to monitor the observed signal strength of candidate cells relative serving cell signal strength. An alternative is to instead consider the received signal quality, but this is not in the 3GPP ANR description. When the relative difference meets a configured criterion, an event-triggered measurement report is signaled to the serving eNB, identifying the target cell by its PCI. Handover is prepared and executed over X2 or S1, informing the serving eNB about access information that the mobile shall use when accessing the target eNB. This mobility control information is conveyed to the mobile, which confirms the handover towards the target eNB. Figure 4 illustrates the signaling and defines the *handover duration*.

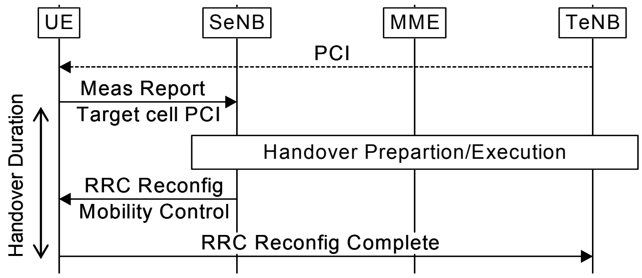

Figure 4. RRC signaling to support handover from a source eNB (SeNB) to a target eNB (TeNB) when the neighbor relation is established. The handover duration is defined from when the target cell is reported until the handover is completed.

In case the PCI is unknown by the serving cell, the mobile is requested via RRC to decode and report CGI. Additionally, the eNB may define discontinuous transmission cycles during which the mobile is ensured that it does not need to monitor serving cell. These time periods can be used to decode CGI of the target cell. An alternative is that the mobile uses autonomous gaps – essentially neglects any serving cell signaling to create a gap for target cell CGI recovery. Figure 5 provides the associated signaling flow. In case X2 is enabled in the network, X2 establishment is also initiated by the reception of the target cell CGI.

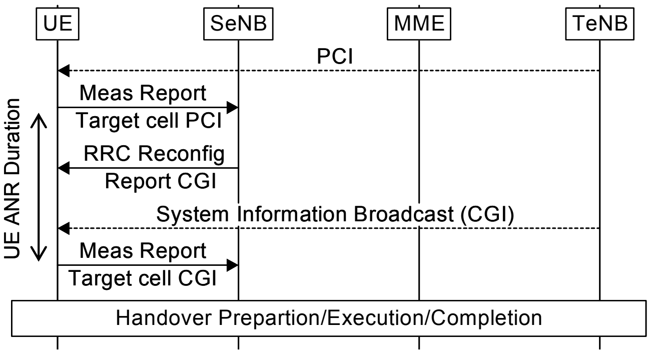

Figure 5. Similar RRC signaling as in Figure 4, but the mobile is requested to decode and report the target cell CGI. The UE ANR Duration is defined as the time between when the target cell is reported until the target cell CGI is reported.

III. RELATED WORK

For an overview on autonomic communication and self-optimization, refer to [5]. In 2G and 3G systems, the mobiles need NRT information in order to report candidate cells, but in LTE the mobiles can operate without such information. Instead, it is the Radio Access Network that benefit from the NRT. Considering NRT 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 neighbor cell relation 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 commercial implementation of the proposed method is briefly discussed in [8].

In WCDMA, the mobiles are capable of detecting and reporting cells not listed in the provided NRT information – detected set reporting (DSR) [4][9]. Soldani and Ore report results on self-optimization of neighbor cell relation lists for UTRA FDD networks using DSR measurements [10]. 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_c/N_0. The neighbors are ranked and the best cells are chosen for deployment in the updated NRT. 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 Stadler developed a procedure for creating NRT reported in [11]. Each base station intersects 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 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. [12] proposed a method for NRT definition, where the service area of the cells is 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 NRT and, as such, generated NRT lists may be erroneous since antenna and propagation models may be inaccurate due to, e.g., unknown terrain data. In contrast to [11] and [12], the current approach for LTE is 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.

The ANR function is based on the assumption that the PCIs are locally unique. 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.[13][14]. Furthermore, LTE PCI conflict resolution is addressed in [15][16].

IV. Field Evaluations

The implemented ANR function has been evaluated in the commercially deployed TeliaSonera Sweden LTE network with 20 MHz bandwidth. The tests were conducted in a pre-launch state cluster without defined neighbor relations, and with a pre-commercial mobile dongle. We divide the evaluation into an UE ANR duration analysis and an ANR function analysis. The area is urban, and the driving speed was between 30 and 50 km/h.

A. UE ANR Duration Analysis

Absolute duration times depend on the mobile and network implementations. Therefore, the durations are normalized to the average handover duration. The data is from a limited drive test with two sites, establishing totally three relations. The UE ANR duration is calculated for each CGI lookup, and the handover duration is computed for each handover between cells where the relations were established prior to the handover.

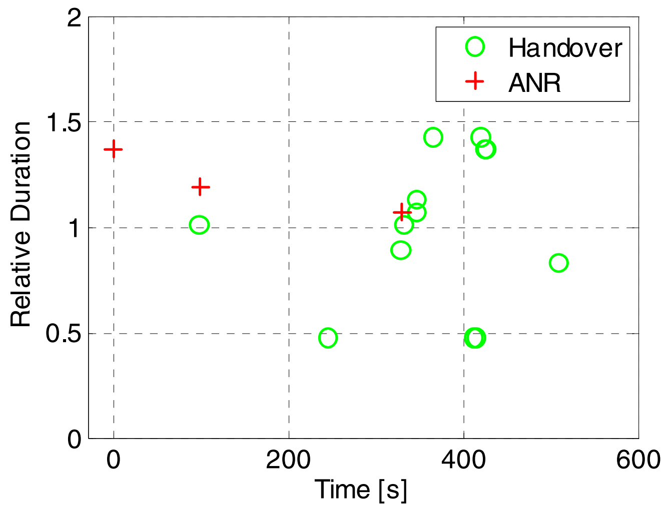

Figure 6. Handover and UE ANR durations relative average handover duration. Approximately, they are of the same order of magnitude. Handover and UE ANR durations are defined in Figures 4 and 5 respectively.

As seen in Figure 6, the UE ANR duration is of the same order of magnitude as the handover duration.

B. ANR Function Analysis

The objectives with the ANR function analysis are to verify mainly two things:

- ANR identifies CGIs of unknown reported PCIs
- ANR does not affect handover performance negatively

The cluster was in pre-launch state, but all the NRT entries were removed, meaning that an eNB could not uniquely identify any reported PCI from the start without the ANR function, except the intra-site cell neighbors which are known. Moreover, X2 establishments were disabled to avoid served cell information sharing between eNBs in order to enforce many CGI lookups.

Figure 7 depicts the ANR function analysis details. The total test duration was 30 minutes, and during this time, 24 inter-site neighbor relations were detected, identified, reported and configured in NRT. In addition, 3 intra-site neighbor relations were also configured. From Figure 7 we see that both obvious and not that obvious inter-site neighbor relations are found. Moreover, some expected relations could not be established due to insufficient coverage in regions where cells would be approximately equally strong as marked in the figure. This was due to the drive route selection restrictions to roads that were available for driving. When coverage is provided, the UE ANR function managed to decode target cell CGI, report it and establish neighbor relations where the mobile detected relevant candidate cells.

This can be seen as an indication that ANR provides functionality such that intra-frequency LTE neighbor relations can be established automatically when needed. Some might even say that handover failures due to ANR is fine, since it is only the first mobile traveling across a new cell border that is affected by the CGI reporting. However, these evaluations indicate that also the first handover of the ANR reporting mobile can be completed successfully.

V. Conclusions

In this paper, we describe 3GPP LTE SON ambitions to support self-organizing networks paradigms for network management. The first SON feature is automatic neighbor relations, ANR, minimizing costly tuning and configuration work performed in the past. 3GPP ANR mechanisms to configure the neighbor relation tables automatically are described thoroughly.

Furthermore, we have presented results from intra-frequency LTE ANR field evaluations in a commercially deployed network cluster in pre-launch state. The results indicate that ANR provides functionality to automatically configure intra-frequency LTE neighbor relations when needed. Moreover, these evaluations indicate that also the handover of the ANR reporting mobile can be completed successfully. During the trial OSS became just an observation tool, instead of its normal operation - configuration and management.

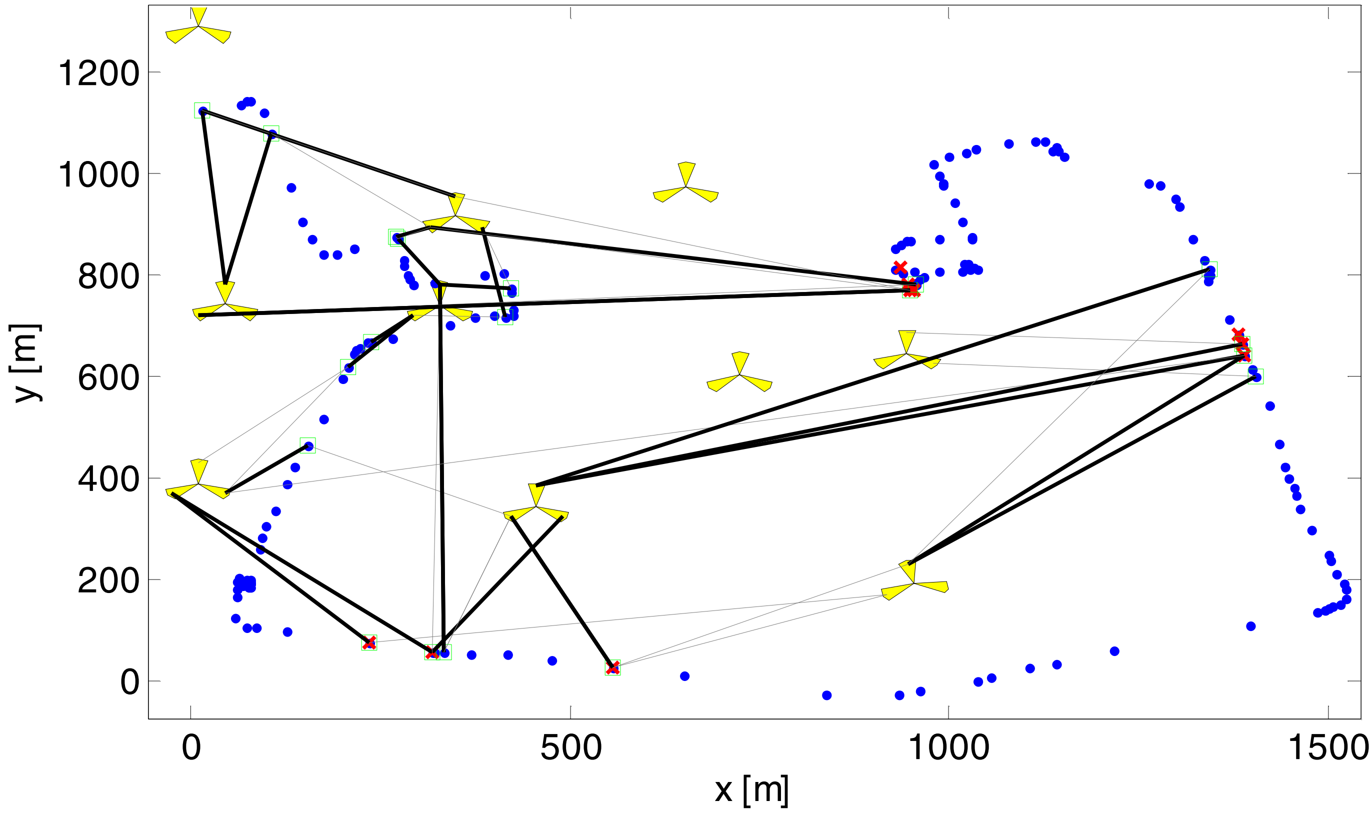

Figure 7. Drive route with marked localized CGI requests/reports (squares). The route begins in the upper left corner and corresponds to good LTE coverage except for the south-western and north-eastern parts (red x). Each reported CGI results in an inter-site neighbor relation between serving cell (thick line) and target cell (thin line). Note that both obvious and not that obvious inter-site neighbor relations are found.

REFERENCES

[1] E. Dahlman, S. Parkvall, J. Sköld, and P. Beming, 3G Evolution – HSPA and LTE for Mobile Broadband, Elsevier, 2007.

[2] 3GPP TS 36.300, v8.12.0, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN); Overall description”

[3] NGMN, “Operator Use Cases related to Self Organising Networks,” ver. 1.53, 2007-04-16.

[4] 3GPP TS 36.331, “Radio Resource Control (RRC).

[5] C. Prehofer and C. Bettstetter, “Self-Organization in Communication Networks: Principles and Design Paradigms,” IEEE Communications Magazine, July 2005.

[6] H. Olofsson, S. Magnusson, M. Almgren, “A Concept for Dynamic Neighbor Cell List Planning in a Cellular System,” IEEE Personal, Indoor and Mobile Radio Communications, Taipei, Taiwan, 1996.

[7] S. Magnusson and H. Olofsson, “Dynamic Neighbor Cell List Planning in a Micro Cellular Network,” IEEE International Conference on Universal Personal Communications, San Diego, CA, USA, 1997.

[8] P. Gustås, P. Magnusson, J. Oom and N. Storm, “Real-Time Performance Monitoring and Optimization of Cellular Systems,” Ericsson Review, No. 1, 2002.

[9] 3GPP TS 25.133, “Requirements for Support of Radio Resource Management (FDD).”

[10] D. Soldani and I. Ore, “Self-Optimizing Neighbor Cell Lists for UTRA FDD Networks Using Detected Set Reporting,” IEEE Vehicular Technology Conference, 2007.

[11] J. Baliosian and R. Stadler, “Decentralized Configuration of Neighboring Cells for Radio Access Networks,” 1st IEEE Workshop on Autonomic Wireless Access (in conjuction with IEEE WoWMoM), Helsinki, Finland, 2007.

[12] F. Parodi, M. Kylväjä, G. Alford, J. Li, and J. Pradas, ”An Automatic Procedure for Neighbor Cell List Definition in Cellular Networks,” 1st IEEE Workshop on Autonomic Wireless Access (in conjuction with IEEE WoWMoM), Helsinki, Finland, 2007.

[13] R.M. Joyce, T. Griparis, G. R. Conroy, B. D. Graves, I. J. Osborne, “A Novel Code Planning Approach for a WCDMA Network,” IEEE Conference on 3G Mobile Communication Technologies, 2003.

[14] S. Kourtis, “Code Planning Strategy for UMTS-FDD Networks,” Vehicular Technology Conference, 2000. M. Amirijo, P. Frenger, F. Gunnarsson, H. Kallin, J. Moe, K. Zetterberg, Neighbor Cell Relation List and Measured Cell Identity Management in LTE, IEEE Network Operations and Management Symposium, Salvador de Bahia, Brazil, 2008.

[15] M. Amirijo, P. Frenger, F. Gunnarsson, H. Kallin, J. Moe, K. Zetterberg, Neighbor Cell Relation List and Measured Cell Identity Management in LTE, IEEE NOMS, Brazil, 2008.

[16] M. Amirijo, P. Frenger, F. Gunnarsson, H. Kallin, J. Moe, K. Zetterberg, Neighbor Cell Relation List and Physical Cell Identity Self-Organization in LTE, IEEE ICC Workshop BWAWS, Beijing P.R. China, 2000.