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Evaluation of the Automatic Neighbor Relation Function in a Dense Urban Scenario

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***Abstract*—Self-organizing network (SON) capabilities are an important feature of coming LTE networks. An automated configuration of neighbor cell lists, the so-called Automatic Neighbor Relation (ANR) function, is one of the first SON features being deployed in commercial networks. In this paper, we present simulation results of the convergence time of the ANR function in a dense urban scenario. We model the corresponding cell identifier measurements and the X2 setup in a detailed way. Our results show that even for sparse user densities, the network achieves good handover performance within the first two hours. We further propose a blacklist method which can significantly reduce measurement overhead in the mobile terminals during the network auto-configuration period.**

I. Introduction

The architecture of the radio access network in LTE, the E-UTRAN, differs from the architecture of UMTS and GSM radio access networks. Instead of a two-level hierarchy with base stations and radio controllers, the LTE radio access network omits the radio controller and only consists of so called enhanced Node Bs (eNodeBs). In this one-level hierarchy architecture, neighboring eNodeBs communicate with each other directly via the so-called X2 interface [1]. Over this interface, neighboring eNodeBs exchange signaling messages, e.g. to prepare and execute handovers or to exchange load information between cells. In case of a handover, user data is forwarded over the X2 interface from the source eNodeB to the target eNodeB until the handover procedure is completed. The X2 interface hence plays an important role to provide seamless mobility in LTE. Whether an X2 interface is set up between a pair of eNodeBs is determined by the neighbor cell entries of their Neighbor Relation Tables (NRT).

Without the Automatic Neighbor Relation (ANR) function, network planning data has to be used to determine the neighbor cell entries of the NRTs of all eNodeBs. Operator's staff would have to manually download these NRTs on the eNodeBs after they have been installed in the field. This procedure is costly and might lead to a sub-optimal NRT configuration, given that the level of detail of network planning data is limited. For instance, it might happen that handovers between a pair of cells occur in a network which could not have been foreseen from the network planning data. Furthermore, every time a new eNodeB is added, again a network planning step and manual configuration tasks are required to update the affected NRTs.

To avoid these problems and to simplify deployment and configuration of LTE networks, ANR functionality was introduced. The ANR function is one of the SON use cases adopted by 3GPP [2] and its operation is detailed in [1]. In brief, the ANR function uses cell identifier measurements performed by mobile terminals to detect neighboring cells, adds these cells to its NRT and establishes an X2 interface between them. We describe this process in more detail in section II-A.

The mode of operation of ANR and its feasibility in hexagonal and non-hexagonal simulation scenarios have already been demonstrated by other authors (see section V for a discussion). In addition to previous work, we present results for a real-world city scenario, which we describe in section III. Our main contribution is the analysis of the convergence time of a network in a realistic scenario with standard-compliant implementation of cell identifier measurements and the exchange of NRT entries during X2 setup. Furthermore, we propose a new method to reduce the measurement burden on mobile terminals during this self-configuration phase.

II. System description

A. Automatic Neighbor Relation function

The intra-LTE ANR function is specified in [1]. If the ANR function is active, every active mobile terminal is configured to report discovered cells if their signal strength exceeds a predefined threshold. This is achieved by configuring a so called *A4 Event* [3] on the mobile terminal. The corresponding threshold is denoted as *A4 threshold*. In comparison to the *A3 Event*, which is used as a trigger for handovers, the A4 threshold will be chosen such that the event occurs before the A3 event. The rationale behind this is to allow mobile terminals to report an A4 event, give the eNodeB some time to set add neighbor relation entry and set up an X2 interface to the target cell, and directly perform a handover afterwards.

In principle, LTE also permits to implement ANR functionality using A3 events only. In this case, an eNodeB would interprete the A3 event as a trigger for both, neighbor cell identification and handover. The neighbor cell identification and X2 interface setup would have to be performed right before the handover to that neighbor is initiated. Given that such realization is prone to timing issues between ANR measurements and the handover procedure, we focus on an ANR implementation based on A4 events.

After an A4 event is configured by its serving eNodeB, the mobile terminal starts measuring the neighbor cells' Physical Cell IDs (PCI). If the signal of a neighbor cell stays above the A4 threshold for a predefined time interval, the so-called *TimeToTrigger*, the terminal reports this neighbor to its serving cell. The measurement report contains the measured cell's Physical Cell Identifier (PCI). The detection of the unique E-UTRAN Cell Global Identifier (ECGI), which is used to globally identify cells, requires a further measurement. Therefore the eNodeB instructs the mobile terminal to determine the ECGI of the neighbor cell with this PCI[1].

The mobile terminal has to decode the neighbor cell's broadcast channel to determine the ECGI [3]. This procedure takes time and is only successful if the signal strength of the candidate cell remains strong enough for a certain amount of time. When the mobile terminal has reported the ECGI to its serving eNodeB, the eNodeB will add this neighbor relation to its Neighbor Relation Table (NRT). The NRT contains one neighbor relation (NR) per neighbor cell, which includes the cell's PCI and ECGI. The eNodeB will then use the ECGI to retrieve the transport layer address of the neighbor cell and, if needed, will setup a new X2 interface towards this eNodeB using the SCTP protocol. The whole cell ID measurement procedure is illustrated in Fig. 1.

B. Intra-LTE handovers and Neighbor Relations

In LTE, for existing X2 interfaces, handovers are performed without involvement of the core network. Specification 36.300 [1] explains the intra-LTE handover procedure: Based on the measurement report received by the mobile terminal (i.e. the A3 event), the source eNodeB decides whether a handover shall be performed. If a handover is initiated, the source eNodeB sends a Handover Request message to the target eNodeB over the previously established X2 connection. After having received an acknowledgment of the target eNodeB, the source eNodeB will instruct the mobile terminal to detach from the old cell and synchronize to the new cell. If the ECGI of the target eNodeB is not known to the source eNodeB, the Handover Request message cannot be sent. Consequently, the source eNodeB cannot initiate the handover procedure and the mobile terminal will eventually experience a radio link failure.

A proper configuration of the NRT is of vital importance for seamless handovers. The most important performance measure for the ANR function is thus the time required to reduce the number of handover failures due to unknown ECGI and therefore non established X2 interface to an acceptable level.

C. X2 Setup

Specification 36.423 [4] includes a procedure for eNodeBs to exchange neighbor information during X2 setup. The X2 Setup Request and Response messages must include a list of neighbor relations with all *direct neighbors* of a cell. A *direct neighbor* cell is any cell to which handovers will be performed. Other NRT entries for cells to which no handovers have been performed yet are not exchanged. This neighbor information exchange during X2 setup provides a means to speed up the configuration of the neighbor relations. The restriction to the exchange of direct neighbor cells avoids that the network is flooded with neighbor relation information between distant cells causing X2 connection setups between all pairs of eNodeBs in the network.

[1]The mobile terminal is also instructed to determine the Tracking Area Code (TAC) and the PLMN ID of the neighbor cell, but this is not relevant to the ANR function here

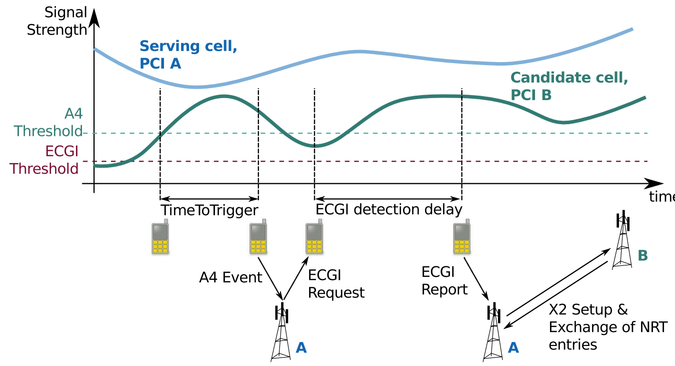

Fig. 1. Illustration of ANR procedure in LTE

D. Reduced Measurement Overhead with Blacklists

While the ANR function is active, mobile terminals report an A4 event to the eNodeB for every PCI that has been detected. Many of those measurement reports are superfluous, in case PCI and ECGI of the reported cell are already known to the eNodeB, i.e. have already been reported by another mobile terminal. These measurement reports consume uplink bandwidth and reduce battery life of mobile terminals. For that reason, ANR functionality should be disabled when the NRTs appear to be settled and activated again if new PCIs are reported within A3 events. If the ANR was not enabled when a previously unknown PCI is reported, handover failures due to missing ECGI of the newly reported PCI would occur. In order to keep ANR active without the above described drawback, we propose to configure an ANR-specific blacklist on mobile terminals, which contains PCIs of cells for which no A4 Events shall be reported anymore. This is in addition to current LTE specifications, which provide a means to configure only a single blacklist on mobile terminals. If the current blacklist was applied to ANR, this would not only prevent A4 measurement reports, but also prevent A3 reports and therefore also inhibit handovers to listed cells [1]. So according to LTE specification, the current blacklist can only be used to prevent handovers to undesired cells, but not to reduce ANR measurement overhead. An ANR implementation that only uses A3 events might also lead to less signaling overhead, but is not considered here for the reasons outlined in section II-A.

III. Simulation Model

Figure 2 shows a best server map of the 3x3 km Frankfurt city area used in our simulations. The scenario consists of 16 tri-sectorized sites, i.e. 48 cells in total. The position of the sites and the orientation of the antenna corresponds

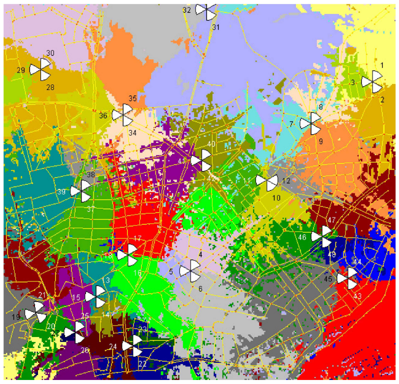

Fig. 2. Best server map of Frankfurt city scenario

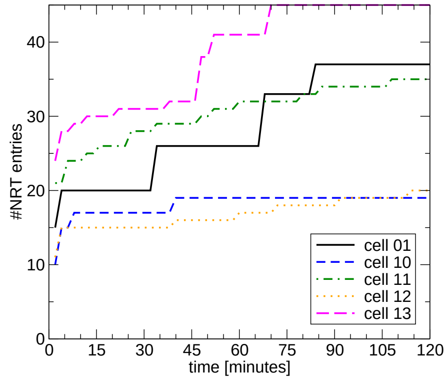

Fig. 3. Growth of the NRT of selected cells

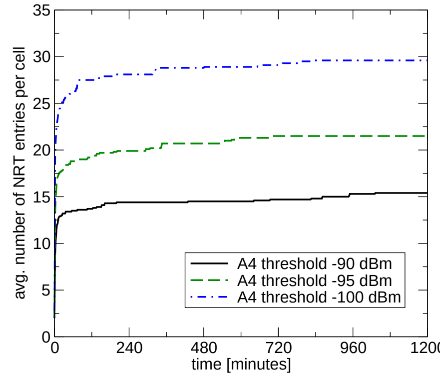

Fig. 4. Average NRT size over simulation time

to a real network configuration. Besides the sites shown in Fig. 2, there are further sites in the surrounding which generate interference, but are not included in the simulation. The signal strength at a given position was determined by a raytracing tool using the Hata path loss model as a basis [5]. Fast fading was added to the signal and corresponds to the typical urban 6 taps Rayleigh fading model described in [6]. The patchy coverage and the restriction to the 48 inner cells might lead to an increased number of handover errors compared to the real deployment. These handover errors occur when mobile terminals would normally perform a handover to one of the cells outside our observation area.

Figure 2 also depicts streets in the observation area. Street data was obtained from the OpenStreetMap project [7]. A mobile terminal is placed randomly on one of the streets and continues moving along this street. At an intersection, the direction of the terminals is chosen randomly. In case of a dead end, the mobile terminal is relocated to another street.

If not stated otherwise, the observation area is populated with 55 mobiles, of which 10 mobiles move at a speed of 3 km/h, 35 mobiles with a speed of 30 km/h and 10 with a speed of 120 km/h. The average mobile terminal density is rather sparse and roughly corresponds to one mobile per cell. Mobile terminals are not distributed uniformly, but are more likely to be located in areas with high street density.

Radio measurements are modeled including L1 and L3 filters. The L1 filter has a sample interval of 1 ms and is implemented as a sliding window over a 40 ms interval. The L3 filter is an IIR filter corresponding to [3], with a sample interval of 40 ms and *k-factor* 9. For ECGI measurements, an ECGI detection delay of 180 ms is assumed, according to the worst case assumption in [8]. During this time, the signal of the neighbor cell must be strong enough, otherwise the ECGI measurement is regarded as not successful.

The TimeToTrigger value is varied between 100 ms and 256 ms. According to [3], a set of 16 discrete values between 0 ms and 5120 ms is allowed. Given that the TimeToTrigger value applies not only to the A4 event, but to all events (including the A3 event for handovers), values in the order of multiple seconds are considered too large. In this case, an A3 event would be triggered very late which might lead to bad handover performance. Very low TimeToTrigger values are not recommended either, as they would lead to large reporting overhead in mobile terminals and reduce battery life.

IV. Simulation Results

We present simulation results obtained by an event-driven downlink system level simulator. At $t = 0$, the neighbor cell lists of all cells only contain the neighboring cells of the same site, i.e. every cell has two entries in their NRT. An important metric to assess ANR performance is the time until the NRTs are complete. However, in a non-hexagonal cell layout, the "completeness" of the NRT is difficult to determine: It might happen that even after the ANR function was active for a long time, a mobile terminal still reports a previously unknown PCI. This is due to fast fading effects and the patchy coverage area in an urban scenario. This usually applies to cells to which handovers occur only very rarely or not at all. In addition, the NRT of a given cell might contain entries for several cells that will never be measured by any mobile terminal in its coverage area. This is due to NRT entries being added during X2 setup. The NRT entries received from a neighbor cell are not necessarily also neighbors of the other cell. Although these NRT entries are not relevant to this cell, they do not constitute notable overhead and can therefore be ignored.

A much more significant metric than the NRT size hence is the time required until the percentage of unsuccessful handovers due to missing ECGI reaches zero or converges to an acceptable level. In the following, we present results on how the number of NRT entries and the percentage of unsuccessful handovers due to missing ECGI develop over the simulation time. To assess the measurement and reporting overhead of the mobile terminals, we measure the number of PCI reports during the first two hours.

A. Illustration of the ANR function

Figure 3 illustrates the growth of the NRT from mobile terminal measurements and the exchange of neighbor relation information during X2 setup. The figure depicts the number of NRT entries for a couple of cells over the first two hours. Depending on the location of the cell, between 10 and 25 NRT entries are set up within the first two minutes. The figure shows

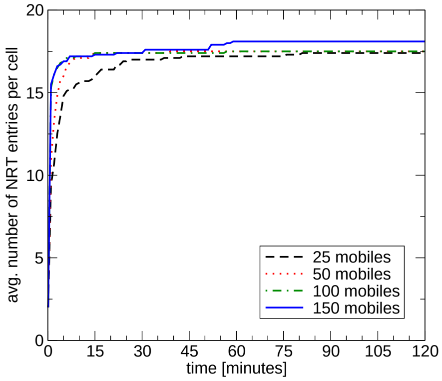

Fig. 5. NRT size with A4 threshold -95 dBm

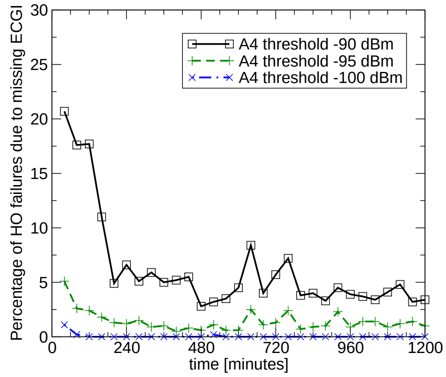

Fig. 6. HO failure rate due to unknown ECGI

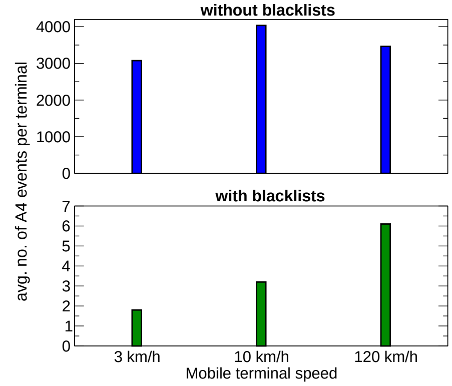

Fig. 7. Number of A4 event reports per terminal

several small and large steps in the growth of the NRT. The small steps correspond to A4 Events and ECGI measurement reports of mobile terminals, i.e. only a single NR entry is added to the NRT . The larger steps (as e.g. for cell 1 at t=35 minutes) correspond to the setup of an X2 connection with exchange of NRT entries, i.e. a large number of NRT entries are added at once.

Over the simulation time shown here, all the NRT entries of cell 1 result from X2 setups. This is typical for cells with low user density. Cell 1 is located at the upper right corner of our observation area and only contains very few street segments. The NRT of cell 1 will have been set up by X2 connection establishments even before the first mobile terminal enters its coverage area.

B. Development of NRT size over time

Figure 4 depicts the number of NRT entries over the simulation time, averaged over all cells in the observation area. The figure shows results for three different A4 threshold values and a TimeToTrigger value of 100 ms. Other TimeToTrigger values in the range of 100 ms to 256 ms did not have any effect on the results. Therefore, we omitted them here and keep the TimeToTrigger value at 100 ms. The size of the NRT depends on the value of the A4 threshold. An A4 threshold of -100 dBm leads to twice as much entries in the NRT as compared to a higher A4 threshold of -90 dBm. Figure 4 also shows that the NRT is growing fast in the first 1-2 hours, but keeps increasing slowly over a very long time. Generally, the higher the A4 threshold, the longer the time until the NRT is complete. However, the configuration of a reasonable A4 threshold is limited towards lower values by a required minimum signal strength for a reliable measurement of the ECGI of a detected neighbor cell.

In addition to the results achieved with only 55 users in the observation area, Fig. 5 shows the growth of the average number of NRT entries for other user densities over the first two hours. It can be seen that higher user densities accelerate the configuration of the NRTs especially during the first minutes after activation.

C. Handover performance

Figure 6 depicts the evolution of the percentage of unsuccessful handovers due to missing ECGI over time. The plot shows the handover failure rate averaged over 40 min. intervals for different A4 thresholds. With an A4 threshold of -100 dBm, after less than two hours no more handover failures due to missing ECGI occur. This corresponds to Fig. 4, where most NRT entries are configured within the first two hours. Although Fig. 4 shows that some NRT entries are added after 10 or more hours, Fig. 6 confirms that these entries are not relevant to the handover performance anymore.

For A4 thresholds -95 dBm and -90 dBm, a few neighbor cells remain for which no A4 event is triggered or ECGI measurement is not successful. The handover failures always happen at the same hot spots between the same pair of neighboring cells, which is a consequence of the patchy coverage area. Although the ANR function with a low A4 threshold prevents handover failures due to missing ECGI, the A4 threshold cannot be set arbitrarily low. A low A4 threshold will lead to a very high number of A4 events and reported PCIs, which constitutes a considerable burden on mobile terminals and consumes uplink bandwidth. In addition, it might lead to an A4 event being triggered, but a subsequent ECGI measurement could fail because of unsufficient signal quality. Besides, receiver sensitivity of the mobile terminal puts a lower bound to the A4 threshold. If the A4 threshold is not low enough to enable the ANR function to automatically configure all relevant neighbor relations, the remaining neighbor relations have to be manually configured. In all configurations shown in Fig. 6, the ANR function was able to significantly reduce the number of handover failures due to missing ECGI within the first few hours after activation.

D. Reduction of Reporting Overhead using Blacklists

In section II-D, we proposed to introduce blacklists to reduce the overhead created by an ANR function with low A4 threshold. Figure 7 presents results on the savings of A4 measurement reports when using blacklists. Without blacklists, the mobile terminals in the observation area in average report around 3000 A4 Events with corresponding PCI values. The shown A4 event numbers are collected over 5 minutes of simulation and would grow linearly with simulation time. By using blacklists, the number of measurement reports are reduced to only a small fraction of this number, which constitutes a substantial saving of battery life on mobile terminals and reduces uplink load. After all relevant (i.e. direct) neighbors have been measured, further A4 events towards rarely seen neighbor cells become fewer and fewer and disappear entirely when NRT is completed. The benefit from an additional blacklist for ANR functionality becomes clearly visible.

V. Related Work

The work closest to our results is [9], where some of the authors were involved as well. The authors presented an analysis of the ANR convergence time for cells layed out on a hexagonal grid. ECGI measurements were modeled in the same way, but in [9] the A4 event was not included. Instead, the A3 event was used as trigger for both handovers and the ANR function. The authors presented results for different user densities. For a density of one mobile terminal per cell, the 95 percentile of the NRT completion time was reached after 45 minutes for 3 km/h mobile and after only 5 minutes with 30 km/h mobiles. This is considerably faster than what we observed in the Frankfurt scenario. We believe this is due to the large differences between a hexagonal cell layout with unconstrained mobility and our Frankfurt city scenario. In contrast to our results, [9] reported much higher handover failure rates. The reason for this probably is the usage of the A3 event as trigger for the ANR function. The A4 event was introduced in 3GPP to leave mobile terminals enough time to report a new PCI, perform eNodeB triggered ECGI measurements, let the eNodeB set up the X2 interface and perform a handover on appearance of a subsequent A3 event. Using only the A3 event, the time required for the above procedure probably is not sufficient and as a result, handovers will fail more often.

The authors of [10] propose an ANR function together with algorithms to ensure locally unique PCIs. They performed simulations on a realistic macro cell scenario with over 200 cells. The focus of this work was on PCI conflict resolution. They showed that their algorithms configure non-conflicting IDs and that the NRT reaches a steady state. However, they did not present results on NRT completion time or handover performance. In [11], the focus is on a framework for visualization of SON algorithms. The authors also focused on PCI conflicts. No results on the time to configure NRTs were presented. The authors of [12] presented an alternative way to achieve an initial configuration of the NRTs. They propose to use an eNodeB scanning technique, were the eNodeBs try measure their neighbors by themselves. The approach was designed for pico or femto cells being deployed in an area with already existing macro cells. It is not comparable to the ANR function evaluated here.

VI. Conclusion

The automated configuration of neighbor cell lists, the so-called Automatic Neighbor Relation (ANR) function, is one of the first SON features being deployed in commercial networks. We presented simulation results of the convergence time of the ANR function in a dense urban scenario. Our results show that the neighbor relation table converges and that handover performance reaches the steady state within at most two hours after activation even for sparse user densities. We found that the A4 threshold is an important parameter for proper operation of the ANR function. While a higher A4 threshold leads to bad handover performance, a lower threshold increases the number of unnecessary measurement reports and thus wastes energy on mobile terminals. To still reduce measurement reporting overhead for mobile terminals despite a low A4 threshold setting, we propose to introduce a blacklist based mechanism for PCI reporting. In contrast to the current LTE specifications, these blacklists must not prevent handovers, but only prevent the reporting of PCIs whose ECGIs are already known to the serving eNodeB.

VII. Acknowledgment

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