Automatic Neighbor Relation Penetration Probability Prediction

Yingzhe Li, Li Ji, Li Yang
Wireless Network Research Department
Huawei Technologies Co., Ltd.
Shanghai, China
{yingzhe.li, lily.jili, levi.yangli}@huawei.com

Abstract—**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. From the operators' point of view, it is beneficial to know how many ANR enabled UEs should be activated to help the full ANR list configuration. In other words, it is important to predict, given a fixed percentage of ANR enabled UEs, how much time is needed to finish the establishment of neighbor relation list. In this work, we defined an ANR penetration probability prediction method and use this method to, calculate the probability of UE detecting a neighbor relationship based on the number of ANR capable UE number and other related network parameters which can be obtained from the network operators. Two prediction cases using this method are discussed and we use simulation to validate the prediction results.**

Keywords- LTE; Self-organizing networks; Automatic Neighbor Relation; ANR penetration; prediction

I. INTRODUCTION

The Long Term Evolution (LTE) radio access network is based on a flat architecture [1]. Each cell is served by an evolved Node Bs (eNodeB), and handover of UEs between cells can be handled by the Mobility Management Entity (MME) via the S1 interface, or directly by the eNodeBs via the X2 interface [2, 3]. The X2 interface hence plays an important role to provide seamless mobility to UEs in a LTE network. 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, NRTs have been populated using cell planning tools by means of coverage predictions before the installation of a base station [4, 5]. Prediction errors, due to imperfections in map and building data, have forced the operators to resort to drive test to exhaust the coverage area, identify all handover regions and manually configure then download these NRTs on the eNodeBs. This procedure is costly and might lead to a sub-optimal NRT configuration.

As one use case of Self-Organizing Networks (SON), the ANR is defined in 3GPP specification [1] to avoid this problem and to simplify deployment of LTE networks. While the operators are freed from heavy field measurement works by ANR, they face questions as: How many UEs with ANR function should be used/activated? How much time is needed to optimally populate a NRT? These questions are significant for operators to optimize the network. To answer these questions, we presented an ANR penetration probability prediction method and validate its effectiveness in a LTE network through simulations.

Here, the ANR penetration is defined as the ratio of neighbor relations established by ANR function to all the neighbor relations in a specific network.

The remainder of the paper is organized as follows. Section II gives an overview of ANR function. Section III presents the ANR penetration probability prediction method. Then two prediction cases are discussed in section IV. In section V we compare ANR penetration prediction results against simulation results. Finally the conclusion is drawn in section VI.

II. AUTOMATIC NEIGHBOR RELATION FUNCTION

3GPP had specified the intra-frequency LTE ANR function in [1]. If the ANR function is enabled, every active UE is configured to report discovered cells to its serving cell if their signal strength exceeds a predefined threshold, which is calledA3/A4 event [3]. This functions to allow UEs to help eNodeB add neighbor relation entry in NRT and set up an X2 interface to the target cell. The detail procedures are as follows.

After an A3/A4 event is configured by its serving eNodeB, the UE starts measuring the neighbor cells' Physical Cell IDs (PCI). If the signal of a neighbor cell stays above the A3/A4 threshold for a predefined time interval, i.e. Time To Trigger (TTT), the UE reports this neighbor's Physical Cell Identifier (PCI) to its serving cell. If this PCI does not exist in the serving cell's NRT, the eNodeB instructs the UE to read the unique E-

UTRAN Cell Global Identifier (ECGI) of the new neighbor cell with this PCI. When the UE has found out the new neighbor cell's ECGI, the UE reports the detected ECGI to the serving cell eNodeB, and the eNodeB decides to add this neighbor relation. If needed, the eNodeB will setup a new X2 interface towards the neighbor eNodeB using the SCTP protocol.

The procedure for eNodeBs to exchange neighbor information during X2 setup had been specified in 3GPP TS 36.423 [3]. The X2 Setup Request and Response messages 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.

III. ANR Penetration Probability Prediction Method

A. *Discription of parameters used*

The parameters which are used in the ANR penetration probability prediction are listed in TABLE I. Note that, all the parameters can be obtained directly or indirectly from the network operator.

TABLE I. PARAMETERS AND SYMBOLS

Parameter	Symbol
Number of eNodeBs	I
Number of cells	J
Number of direct neighbors per cell	K
Number of UEs with ANR function in the network	L
Activity model	$q(t)$
Average handover times of one session during a unit period	r
Probability of UEs obtain CGI successfully	s

For simplicity, consider we assume an eNodeB serves three cells ($J=3I$.), so there are $J \cdot K$ direct neighbor relations in the network (a cell can has $K=9\sim 12$ direct neighbors). Note that under this assumption, two direct neighbors of each cell are "intra eNodeB" neighbors which are known, there are $M=J\cdot(k-2)$ direct neighbor relations to be detected in the network.

Firstly, for ANR capable UEs (L UEs in the network), only when they are in active mode, they will be able to detect the CGIs of neighbor cells and help build the neighbor relations. At a certain time t, the rate of active UEs is modeled as a activity model $q(t)\in[0,1]$. Normally, this rate varies from 0% to 30% within one day. The operators can provide the activity model through traffic session statistics.

Secondly, only the UEs which across the cell boundaries have opportunities to read the neighbors' CGIs with a success rate $s\in[0,1]$. We define $r\in[0,+\infty)$ as the average handover times of one session during a unit period. This parameter depends on cell coverage size as well as the average UE speed, and can be obtained from operators session statistics.

So in unit period, the times which UEs can obtain the CGIs successfully is

$$N(t)=L\cdot q(t)\cdot r\cdot s \tag{1}$$

But $2/K$ direct neighbors are intra eNodeB, they are already in NRT when the eNodeB startup. There is no contribution if UE obtain the intra eNodeB neighbor's CGI. Considering this exception, the times which UE obtain effective CGIs is

$$N_{eff}(t)=\left(1-\frac{2}{K}\right)\cdot N(t) \tag{2}$$

In given period T, all the times which UE obtain effective CGIs can be described as

$$\mathbb{N}_{eff}=\sum_{t}^{T}N_{eff}(t) \tag{3}$$

B. *Probability prediction*

We assume the probabilities of UE obtaining each neighbor relation are equal. When UE have an opportunity to read a neighbor relation, i.e. obtain a certain CGI of neighbor cell, the probability of a specific neighbor relation being read is $1/M$, as in total there are M neighbor relations

Firstly considering one neighbor relation in a unit period, the probability of a specific neighbor relation being read n times can be described as

$$p_n=C_{N_{eff}}^{n}\cdot\left(\frac{1}{M}\right)^{n}\cdot\left(1-\frac{1}{M}\right)^{N_{eff}-n} \tag{4}$$

where C denotes the combination operator, and $C_{N_{eff}}^{n}$ can be calculated as

$$C_{N_{eff}}^{n}=\frac{N_{eff}!}{n!(N_{eff}-n)!} \tag{5}$$

(4) is a binomial distribution. If M and N_{eff} is big enough, and N_{eff}/M is constant as in a big stable network, (4) can be approximated to Poisson distribution [6] as followed

$$p_n \approx \frac{\left(\frac{N_{eff}}{M}\right)^n \cdot e^{-\left(\frac{N_{eff}}{M}\right)}}{n!} \tag{6}$$

Especially, the probability of a specific neighbor relation which will never be read is

$$p_0 = (1-\frac{1}{M})^{N_{eff}} \approx e^{-\left(\frac{N_{eff}}{M}\right)} \tag{7}$$

Secondly considering all the neighbor relations in the network, if there are m no-read neighbor relations, the ANR penetration is $\eta = (M-m)/M \in [0,1]$. In a unit period, the probability of η is

$$P(\eta) = C_M^m \cdot (p_0)^m \cdot (1-p_0)^{M-m} \tag{8}$$

(8) is a binomial distribution, and can also be approximated to Poisson distribution as:

$$P(\eta) \approx \frac{(M \cdot p_0)^m \cdot e^{-M \cdot p_0}}{m!} \tag{9}$$

Especially, if ANR penetration is $\eta = 100\%$, i.e. $m = 0$, the probability of this situation is

$$P(1) = (1-p_0)^M \approx e^{-M \cdot p_0} \tag{10}$$

Thirdly, If we consider a period T instead of unit period the only change is that we shall substitute N_{eff} with $\mathbb{N}_{eff}$ in (4) ~ (7).

Overall, the probability of satisfying ANR penetration larger than $\eta = (M-m)/M$ is

$$P(\geq \eta) = \sum_{x=\eta}^{100\%} P(x) \tag{11}$$

where $P(x)$ can be calculated with (4) ~ (9).

C. *Exchanging NRT information via X2*

The eNodeBs exchange neighbor relations information during X2 setup [4]. The X2 Setup Request and Response messages must include a list of neighbor relations with all direct neighbors of a cell. An example is illustrated in Figure 1. An UE with ANR function moves from cell C_1 to C_2, and across the boundary NR_1. After UE detects C_2 which is a direct neighbor of C_1, C_1 will add C_2 to its NRT and mark it as direct neighbor relation. During X2 setup, C_2 also adds C_1 to its NRT and marks it as direct neighbor relation. At the same time, C_1 and C_3 add each other to their NRTs because of the direct neighbor relation NR_2 between intra-eNodeB cells C_2 and C_3. C_1 and C_3 do not build the direct neighbor relation until a UE across the boundary NR_3 and obtain the neighbor relation between C_1 and C_3.

Consequently, if X2 NRT information exchange is considered, the total direct neighbor relations to be detected in the network will be halved, i.e. $M_{X2} = M/2$.

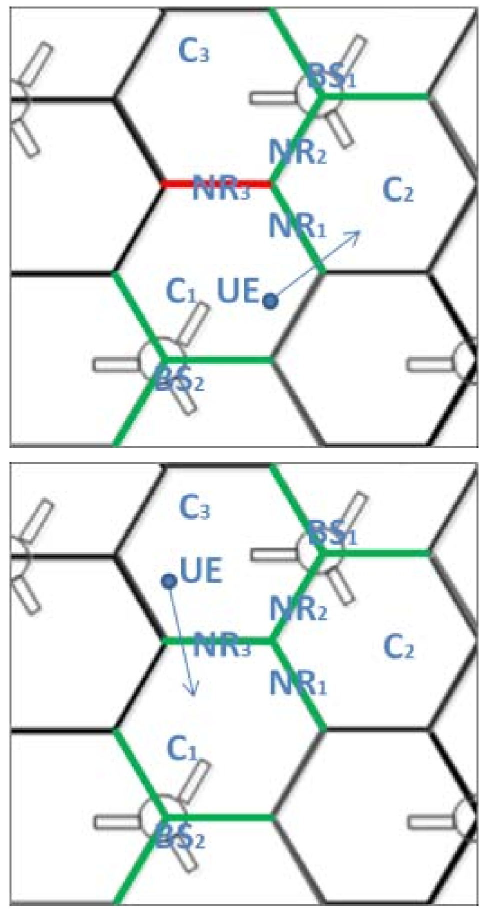

Figure 1. NR buildup by UE detection and X2 exchanging

IV. PREDICTION CASES RESULTS

We studied two cases to calculate the ANR penetration prediction results. The parameters of the two cases are list in TABLE II.

In TABLE II, the activity coefficients which we use in Case 1 and Case 2 vary from 0% to 30% in one day as Figure 2 shows. There were three peaks at 10:00, 15:00 and 20:00, while almost no activity at 2:00.

TABLE II. CONFIGURATIONS OF CASES

Parameter	**Symbol**	**Configuration**	
		Case 1	***Case 2***
Number of eNodeBs	I	50	1000
Number of cells	J	150	3000
Number of direct neighbors per cell	K	9	12
Number of UEs with ANR function in the network	L	20	To be predicted
Activity model	$q(t)$	0~30%	0~30%
Average handover times of one session during a unit period	r	0.9	0.5
Probability of Ues obtain CGI successfully	s	0.67	0.67
ANR buildup period	T	To be predicted	1day, 2day
X2 interface	-	On	On
Request ANR penetration	$\geq \eta$	99%, 100%	99%, 100%

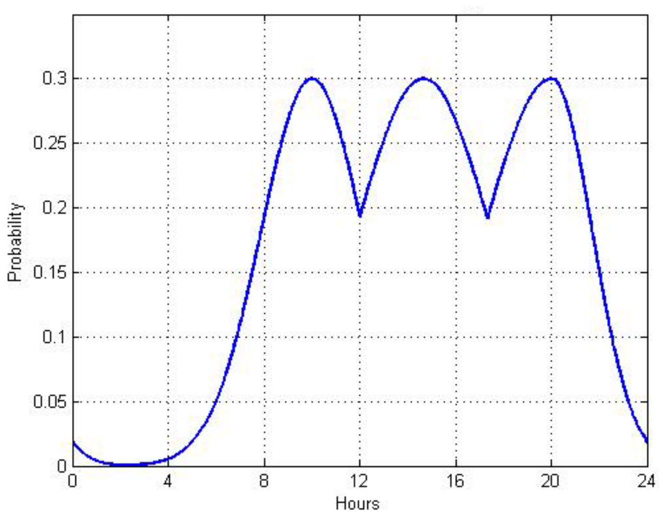

Figure 2. Traffic model in one day

A. *Results of Case 1*

The results of Case 1 are shown in Figure 3. The x-axis shows the time for NRT establishment through ANR, while the y-axis shows the probability of satisfying ANR penetration rate η. In this case, the rate of sessions which need handover per minute is 0.9, r=0.9. This is because most UEs move rather fast and the 90% UEs across a cell boundary during 1 minute.

The red line is the prediction result of η=100%. After 3 days, the red line almost reaches 1. This means that 20 UEs in Case 1 with ANR capability can finish the NRT establishment for the network with 50 eNodeBs within 3days. If the expected ANR penetration is $\eta \geq$ 99%, it only needs 1.5 days.

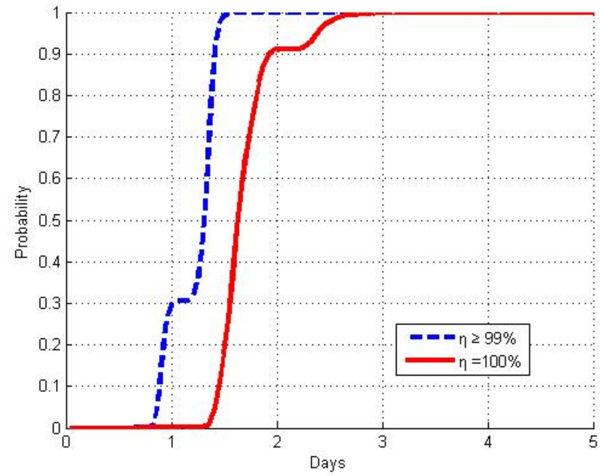

Figure 3. The results of Case 1

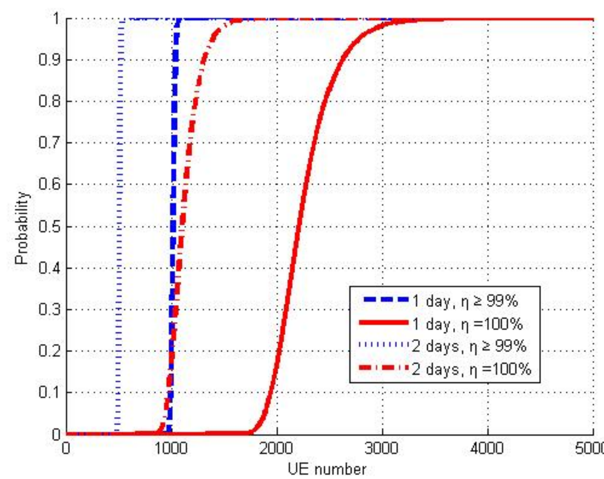

Figure 4. The results of Case 2

B. *Results of Case 2*

The results of Case 2 are shown in Figure 4 where x-axis show the number of ANR capable UEs in the network. In this case, the rate of sessions which need handover per minute is 0.5, i.e. r=0.5, which means 50% of all UEs will across a cell boundary during 1 minute.

If only 1 day is allowed to establish NRTs with 100% ANR penetration rate, 3500 ANR capable UEs will be needed for the network of 1000 eNodeBs. . In average, 3.5 UEs with ANR capability is needed for each eNodeB. If the requested ANR penetration is $\eta \geq$ 99%, it needs about 1000 UEs. If the time allowed for NRT establishment is extended to 2 days, the required UEs number will be halved.

V. SIMULATION AND COMPARISON

To validate the ANR penetration probability prediction method, we designed a simulation which is similar to [7].

In the simulation, there are 7x7 hexagonal cells with 100m radius, with in total 240 neighbor relations. 20 UEs are randomly distributed in the cells, and randomly move with 10kmph speed. The rate of UE in active mode is 30%, and probability of UE detecting CGI successfully is 60%. 1000 times simulations are done to obtain the cumulative distribution function (CDF) of the needed time for full detection (η =100%) of NRs, which is shown in Figure 5 as red dash-dot line while blue lines show the corresponding prediction results.

If the UE move across the cell along the cell diameter, the minimum rate of sessions which need handover per minute can be calculated as $r_{\min}$ =167m/200m=0.83. The other side, the average cell chord is 128m, so the average rate of sessions which need handover per minute is r_{avg} =167m/128m=1.3. The prediction results of 100% ANR penetration with $r_{\min}$ and r_{avg} are shown in Figure 5 as blue solid line and blue dash line.

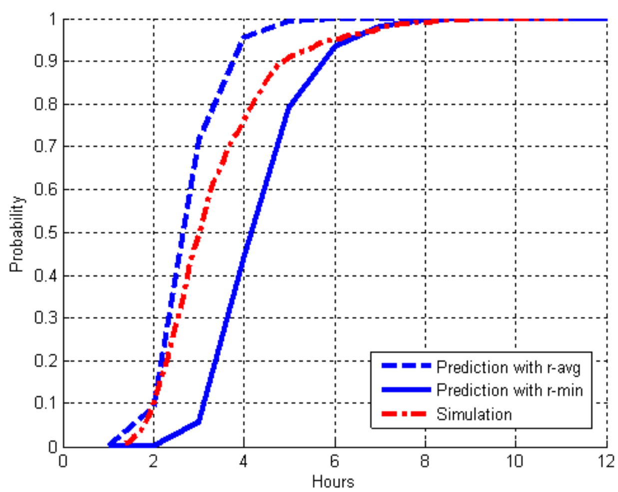

Figure 5. Simulation and prediction comparison

Comparing the simulation results and prediction results, we find that the prediction results with r_{avg} is close to simulation results, except the parts after 3 hours. This is because that actual r of simulation is not constant, and it could be bigger or smaller than r_{avg} some times. If the actual r of simulation is smaller than r_{avg} of prediction, the prediction results would be earlier. If we use the $r_{\min}$ in the prediction, as all the r for simulations are bigger than $r_{\min}$, the simulation results show an earlier completion of NR establishment than the prediction results.

VI. CONCLUSION

The automated configuration of neighbor cell lists, the so-called ANR function, is defined in 3GPP specification as one use case of Self-Organizing Networks. The ANR free the operators from costly drive test works. To estimate ANR penetration which indicates how much NR of one network are established by ANR function, we use an ANR penetration probability prediction method to calculate the probability relationship between ANR penetration, UE number and time for UE detection, based on the parameters which can be obtained directly or indirectly from network operator. Two prediction cases are studied and the results are validated with system simulations

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