A Dynamic Hysteresis-adjusting Algorithm in LTE Self-Organization Networks

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***Abstract*—Handover Parameter Optimization (HPO) and Load Balancing (LB) are two Self-Organization network (SON) aspects which aim at improving LTE system handover performance and user's satisfaction respectively. However, there is often counteraction between LB and HPO, because LB would increase the frequency of inter-cell handover and correspondingly increase the possibility of handover problems. Furthermore, most of the LB and HPO jointly optimization methods don't consider the network allowed maximum radio link failure (RLF) ratio, which would increase the possibility of call dropping although the cell loading is balanced. In this paper we introduce the network allowed maximum RLF ratio as a key indicator and a dynamic hysteresis-adjusting (DHA) method to harmonize the two aspects. Furthermore, we take the realistic network situations into account to obtain a more reliable result. The proposed method is evaluated by a series of system-level simulation which witnesses an improvement in handover performance and number of satisfied users in LTE networks.**

Keyword- self-organization networks; load balancing; handover parameter optimization; Long Term Evolution; jointly optimization

I. INTRODUCTION

The advent of Long Term Evolution (LTE) specifications [1], which defined an enhanced radio access network and an evolved core network, has had a significant impact on the ever-growing demand for packet-based mobile broadband systems, especially in the aspect of transmission bandwidth and quality of service (QoS). In existing mobile networks, many parameters are often adjusted manually based on the corresponding operation needs. Thus the adjustment of a great number of parameters in LTE network deployment will become a heavy burden to network optimization. So Self-organizing network (SON) technology is promoted by the international standardization body 3GPP and operators' lobby Next Generation Mobile Networks (NGMN), in which the parameters are automatically selected and adjusted to achieve optimal system capacity and coverage.

Moreover, parameter-tuning requires a comprehensive systematic approach as there might be contradiction between one another, thus jeopardize the overall performance. For example, as one of the most important self-optimization algorithms for LTE networks, Load Balancing is defined as an automatic way to resolve the overloading by shifting traffic towards the light-loaded cells nearby, consequently making the use of the radio resource more efficiently across the whole network. One possible way to balance the network load is to adjust the network control parameters in such a way that over-loaded cells can offload the excess traffic to low-loaded adjacent cells, whenever available.

However, this action might introduce additional handovers, which might cause bad handover performance, leading to the result that system would adjust handover parameters to ameliorate the situation, which might be in contradiction to the aim of load balancing.

This paper introduces a network allowed maximum radio link failure ratio and a new dynamic hysteresis-adjusting method to avoid this phenomenon. The rest of this paper proceeds as follows. To begin with we will provide a brief background on the related concepts: Load balancing (LB) and handover parameter optimization (HPO) in section II. Section III proposes the new dynamic adjusting algorithm, in which the hysteresis is tuned accordingly to harmonize LB and HPO. In section IV, a system-level simulation model is presented and simulation results are analyzed. The paper is brought to a conclusion in section V.

II. LOAD BALANCING AND HANDOVER PARAMETER OPTIMIZATION

A. Load Balancing (LB)

In LTE, the traffic request of some cells may be far higher than acceptable level, named as "hotspots", while some of the other cells may have enough resources to serve more users, which would result in load unbalance and user dissatisfaction. Therefore, allocating the radio resources through load balancing to improve the network quality draws much attention.

In existing load balancing methods, when the load ratio of a served cell exceeds a preset threshold, it would first select the cell with the smallest load ratio from its neighbor cells as the target to execute load balancing. Then the source cell would select the appropriate users in the overload cell to switch.

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Finally the users are adjusted (handover, reselection, etc.) to the target cell to achieve load balancing between cells.

There has been a lot of research done to equalize load among cells. A traditional handover approach to achieve load balancing is presented in [2], which chooses the highest physical resource block (PRB)-utilization cell as the source cell, and the lowest PRB-utilization adjacent cell as the target cell. In [3], the cell-specific offset is adjusted automatically based on the source cell load and its neighboring cell condition. In [4], a method for load estimation after handover is proposed, which is based on SINR prediction and user signal quality measurement.

B. *Handover Parameter Optimization (HPO)*

As presented in [5], handover is one of the key procedures for ensuring that the users move freely through the network with continuously being connected and being offered services. Since its success rate is a key indicator of network performance, it is vital that this procedure happens as fast and as successfully as possible.

Handover parameter optimization (HPO) aims at adjusting the handover parameter, such as inter-cell singal offset and handover hysteresis, according to the handover performance indicators (HPI) which reflects the current handover performance of the network. The main HPI include the number of HOs that are initiated but not carried out to completion (HO failures), repeated back and forth handovers between two base stations ("ping-pong" HOs) and radio link failures(RLF) due to unsuccessful handover.

C. *Interactions*

According to [6], a load balancing handover event is initiated when UE detects that a neighbor cell offers a better signal quality than its current serving cell. This condition is referred to as measurement event A3 [13], which is formulated as (1).

$$Ms + Oc < Mt + Hyst \tag{1}$$

Where *Ms* and *Mt* are the signal strength or quality values for serving cell S and target cell T, *Oc* is specific offset and *Hyst* is cell specific hysteresis value. *Mt*, *Ms* are expressed in dBm in case of RSRP, or in dB in case of RSRQ. The offset *Oc* is a cell pair specific value, which shifts the actual cell border, i.e. the point at which signal quality to both eNB is regarded as equal, to one or the other cells direction.

As presented in [7], the two SON aspects (LB and HPO) described in the previous sections may not control exactly the same parameters but they both influence the handover decisions as the parameters cannot be decoupled.

When a overload cell is detected, the LB function adjusts the handover offsets to adjacent Target eNB (TeNB), thus shifting the cell border to make the handover area enlarged. Then some users would be out of the overloaded Source eNB (SeNB) and forced to handover to TeNB. So the number of handover inevitably increases and thus may cause the radio link failure, handover failure and ping-pong handover rise, especially for the user with long distance and bad signal quality to TeNB, i.e. worse the HPIs. In this situation, the HPO algorithm might be triggered to adjust the hysteresis, which might be in contradiction to the aim of load balancing and cause ping-pong handovers of the users previously handed over. [7] proposes a combination of all HPIs into one figure and a coordination of LB and HPO algorithms, but the combination does not take the realistic limitation of RLF ratio into account. A better idea for this purpose is to restrain load balancing to the direction of handover performance optimization. So in this paper, we aim at finding a comprehensive method to harmonize these two aspects in order to reach a better overall performance for the entire system.

III. Dynamic Hysteresis-Adjusting Method (DHA)

The handover performance indicator (HPI) includes radio link failure (RLF) ratio, handover failure ratio and number of ping-pong handovers, which all reflect the current network handover performance. However, ping-pong handover only increases the handover number without making the user's connection drop, and handover failure is not as fatal as RLF because it still allows the users to be linked with their previous eNB. Only RLF causes the call drop and make the user service interruption. So RLF is usually regarded as the most important indicator in HPI. In realistic networks, the allowed maximum RLF ratio is usually limited to a value γ which is approximately 10%, according to the network operators' requirement for network service performance. The network with a radio link failure ratio higher than γ, will cause a lot of call drops and unacceptable network quality. The operator with such a network situation must perform network optimization immediately. So we will take the most important indicator RLF ratio and its limitation as the guide in the coordination of LB and HPO.

First we would have a briefly review of the radio link failure procedure. As 3GPP LTE specification mentioned [8], when the link quality is declined to bad enough, a Radio Link Failure (RLF) is triggered with interruption in service and possibly a call drop. The UE detects the downlink (DL) radio link quality of the serving cell, which is compared to the thresholds *Qout* and *Qin*. The threshold *Qout* is defined as the level at which the DL radio link cannot be reliably received and corresponds to 10% block error rate of a hypothetical Physical Downlink Control Channel (PDCCH) transmission, while the threshold *Qin* corresponds to 2% block error rate [8]. A generalized RLF procedure is described in Fig. 1. [9]

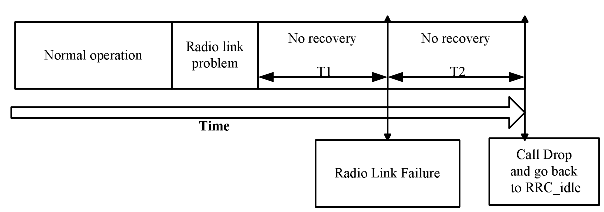

Figure 1. Radio Link Failure

The first phase T1 of RLF is started upon radio problem detection, which corresponds to the *Qout* detection. If the link quality is not increased to the level of *Qin* within the duration of T1, a RLF is triggered. In the second phase T2 the UE may resume activity and avoid going to the RRC_IDLE state if the RRC connection can be still re-established before the timer expired. Otherwise, the RRC connection needs to be released and a call drop happens [9]. T1 and T2 are usually configured by the operator according to the network operation experience.

In this paper, we propose a dynamic hysteresis-adjusting (DHA) method to gain a better coordination between LB and HPO with the limitation of RLF ratio. For a better understanding, a visual interaction and limitation is presented in Fig. 2.

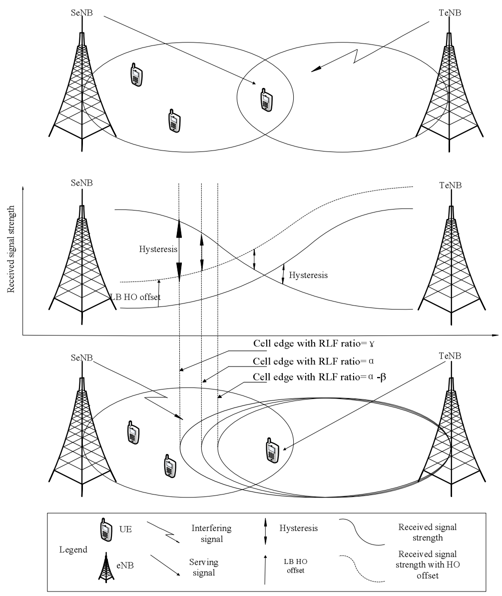

Figure 2. Limited Load Balancing and Handover Parameters Optimization

As shown in Fig. 2, interactions happen when LB shifts or enlarges the handover area to reduce the overload, which deteriorate the radio link quality. For the premise of network allowed maximum RLF ratio <γ to ensure a normal network function, restrain of load balancing should be executed in certain jointly optimization situations. Therefore, two parameters for this purpose are firstly proposed.

α is defined as the lowest level at which RLF ratio is acceptable. α can be set below γ according to the need of the network operator. If RLF ratio is higher than α, operator should pay more attention to the network handover performance and take effective measure to avoid the RLF ratio to finally reach γ, such as stopping or restraining load balancing. On the other hand, when RLF ratio is below α, we can execute LB and HPO in parallel. In this paper, we use 8% for α in simulation.

β is an offset of α ranging from 0 to α , which is used to give a strength adjustment space of LB. When RLF ratio<α-β , LB and HPO can be executed separately without concerning the influence to the other aspect. If RLF ratio exceeds α-β , the strength of LB shall be attenuated to decrease the minus effect to handover. It is also up to the network operators to decide β value based on actual network requirement. In this paper we use 1% for β in simulation.

The proposed new coordination method, DHA, proceeds as shown in Fig. 3.

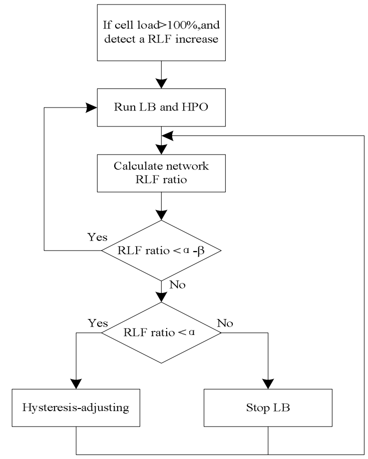

Figure 3. Dynamic hysteresis-adjusting method

When RLF ratio<α-β, LB and HPO are executed as normal separately, nothing else should be done.

When α-β<RLF ratio<α, DHA would adjust the hysteresis iteratively according to (2) to make the two aspects function harmonious, i.e. the LB algorithm is restrained by changing the hysteresis parameter to not continue to jeopardize the HPO algorithm.

$$Hysteresis\ (i) = \begin{cases} Hysteresis\ (i-1) + step, \text{condition } a \\ Hysteresis\ (i-1) - step, \text{condition } b \end{cases} \quad (2)$$

In (2), condition *a* represents the situation that the RLF ratio decreases compared to last adjustment, whereas condition *b* represents the RLF ratio increases compared to last adjustment. *Step* is the adjustment at each time for iterative adjusting of hysteresis. For example, if load balancing sets a high offset to facilitate the handovers from overloaded cells to neighbor cells, resulting with a degrade of handover performance (more users will encounter radio link failure before they could handover to the TeNBs stably, as the change of the handover area). In this case DHA would increase the hysteresis in the overloaded source cell or lower the hysteresis in target cells to make compensation. Just as proposed in (1), we can moderate the overweening load balancing by the hysteresis and thus improve the overall handover performance at the same time.

When RLF>α, DHA would stop LB and only optimize the handover parameter to improve the handover performance and keep the radio link failure ratio below γ.

After RLF declined to below α-β, the restrain of LB would be stopped and run both LB and HPO as before to reach the lowest number of unsatisfied users in the premise of an available radio link situation.

IV. SIMULATIONS

System-level simulations for a LTE cellular network are made to evaluate the performance of the proposed method in terms of number of unsatisfied users and handover performance. Handover failures and ping-pong handovers are also compared. In the simulation results we represent performance of reference, both LB+HPO, and the DHA proposed above. In the reference case, both HPO and LB algorithms are disabled.

A. Layout, Scenarios, Parameters

A regular hexagonal 19 cell layout with an inter site distance of 1000m and wrap around technique is used to avoid boundary effects (cf. Fig. 4). Each cell has one base station situated in the center with no sectors divided. We assume that the LTE capacity will be 30 UEs per cell (assuming 20MHz bandwidth). We set the simulation time to 20 minutes and each of the two aspect works with a certain optimization interval: 1s for LB and 30s for the HPO. The main simulation parameters are given in Table 1.

TABLE I. SIMULATION PARAMETERS

System bandwidth	20MHz
Cell layout	Hexagonal grid, 19 cell sites,57sectors with wrap-around technique
Inter-site distance (ISD)	1000m
Pass loss	-38.4-35.0log10R(distance between UE and eNB)
Shadow fading	Log-normal with standard deviation 8dB
Shadow fading correlation distance	10m
Antenna gain	-7dB
eNB Tx antennas	1 per cell
UE Rx antennas	2
eNB Tx power	46dBm
Traffic model	CBR 0.5Mbps full buffer traffic

B. User Position

In order to show the necessity of LB and HPO, we artificially create heavy load concentration in our 19 cells network. A vehicle carrying 50 users (hotspot) is moving across the network on a predefined path, and unsatisfied users would appear when the hotspot is moving into the cells. The number of background users has been set to 15 users per cell, i.e. 285 background UEs are uniformly dropped according to the settings in Table 2. Each UE engages a random walk in the areas and changes direction every 5 second. The path of users in the hotspot is indicated in Fig. 4. The speed of users in the hotspot is 30km/h.

TABLE II. UE DISTRIBUTION

Number of background users unit	285
Number of users in the hotspot	50
Distribution in each cell	Uniform distribution
Cell capacity	30UE
UE speed	30km/h

C. Results

Average radio link failure ratio and average number of unsatisfied users are evaluated to examine the performance of the proposed dynamic adjusting method.

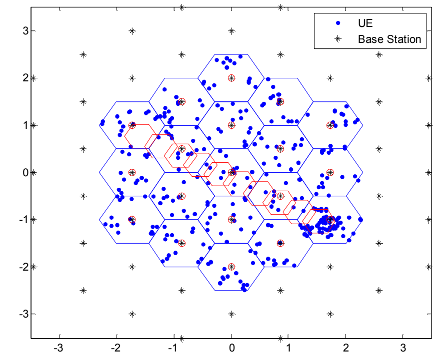

Figure 4. Network model with wrap-around technique

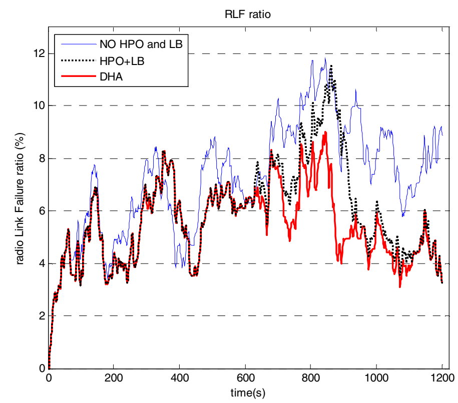

Figure 5. The radio link failure ratio over the 20 minutes

Fig. 5 shows the timeline for radio link failure ratio versus the simulation time. It is visible that DHA has much better radio link status, and keeps the RLF ratio lower than 9% during the simulation time, whereas in the case of reference (no HPO and LB) and HPO+LB, for nearly 12% of the simulation time (140 seconds), the radio link failure ratio is higher than 10% , which is harmful to realistic network. The reason is that in our method, to meet the basic requirement of the network, DHA is triggered to decrease the RLF ratio as quickly as possible when RLF ratio is higher than 8% .

Fig. 6 is the number of unsatisfied users for the whole simulation runtime. As shown in the figure, the unsatisfied users increase to the highest after the hotspot moves to the center, as for central users are harder to execute handover. It can be observed that the unsatisfied users in the case of HPO+LB are similar with that of DHA, sometimes even lower. This is because DHA restrains LB for achieving a better RLF ratio, which resulting in a weakened LB, while HPO+LB proceeds regardless of network radio link quality.

For further evaluation, Table III presents a numerical value comparison of RLF ratio and unsatisfied users during the simulation time.

TABLE III. COMPARISON OF RLF RATIO AND UNSATISFIED USERS

	Scheme	*Max*	*Min*	*Average*	*Variance*
RLF ratio	No HPO&LB	11.80	0	7.23	4.57
	HPO+LB	11.52	0	5.90	3.69
	DHA	8.99	0	5.41	2.27
Unsa-	No HPO&LB	28.39	0	10.22	84.71

tisfied Users	HPO+LB	24.52	0	6.31	55.26
	DHA	24.52	0	7.13	53.96

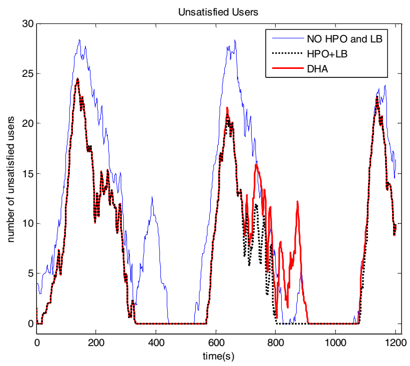

Figure 6. The number of unsatisfied users over the 20 minutes simulation length

In Table III, it is obvious that DHA control the max RLF ratio under 10% and average RLF ratio under 5.5% successfully, which is best in the three algorithms. For unsatisfied user number, DHA obtains the comparable performance with HPO+LB, and much lower than reference. Furthermore, relatively lower variance shows that DHA has a more stable radio link situation for network service.

Another coordination method COO, as mentioned in [7], also provides an optimization for coordination of LB and HPO. COO reaches a lower HPI with higher unsatisfied users than that of HPO+LB, and it also neglects the realistic limitation of RLF ratio. In COO, a weighted sum of RLF, ping-pong and HO failure to calculate HPI and evaluate the current handover performance, while in DHA, RLF ratio is regarded as the HO handover evaluation indicator .

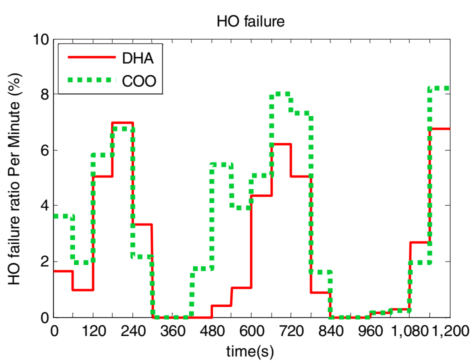

Figure 7. The handover failure of COO and DHA

Actually, simplified indicator calculation method does not represent unsatisfied result. Fig. 7 and Fig. 8 shows the comparison of handover failures and ping-pong handovers in the case of DHA and COO method. It is shown in Fig. 7 that DHA has a lower HO failure ratio than COO in 11 minutes and an equal HO failure ratio in 7 minutes ,which occupy 55% and 35% of 20 minutes simulation. In Fig. 8, the ping pong handover number are equivalent to these two method in 95% simulation time. DHA has more ping-pong handovers only in 1 minute. The results indicate that our method can achieve a comparable performance as that of the weighted sum method (COO), and DHA is much simpler and easier to realize.

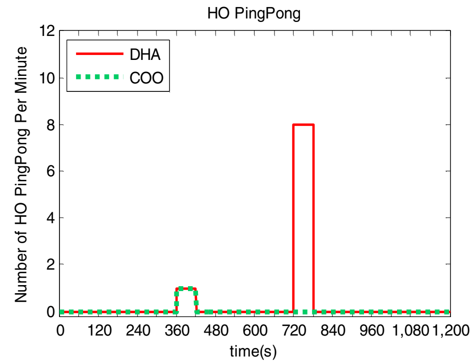

Figure 8. The ping-pong handover of COO and DHA

V. CONCLUSIONS

In this paper, a dynamic hysteresis-adjusting method is presented. With this proposed method, the two SON aspects——load balancing and handover parameter optimization can achieve a better coordination. The new method tunes the hysteresis according to a key indicator，radio link failure ratio, with realistic consideration, thus avoiding the possibility that load balancing has a bad influence on the network performance, for example, causing a higher radio link failure ratio and risk of jeopardizing the normal function of a network. With the proposed method, which is simple and easy to realize, the network handover performance and load balancing effect are both guaranteed compared with conventional solutions.

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