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A Novel Dynamic Adjusting Algorithm for Load Balancing and Handover Co-Optimization in LTE SON

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Abstract With the development of mobile internet and multi-media service, advanced techniques need to be applied in wireless network to improve user experience. Long term evolution (LTE) systems, which can offer up to 100Mbps downlink date rates, have been deployed in USA and Korea. However, because plenty of complex physical layer algorithms are utilized, network planning and optimization become heavy burdens for LTE network operators. Self-organizing network (SON) is a promising method to overcome this problem by automatically selecting and adjusting key parameters in LTE systems. In this paper, we present a dynamic adjusting algorithm to improve both handover and load balancing performance by introducing a weighted co-satisfaction factor (CSF). Analysis and system level simulation are conducted to exhibit the performance improvement of the proposed scheme. Results show that the proposed method outperforms the conventional solutions in terms of the network handover success ratio and load balancing gains significantly.

Keywords self-organization network, load balancing, handover, joint optimization

1 Introduction

The recent remarkable traffic growth in mobile internet requires new wireless communication systems to support higher data rate. Long term evolution (LTE), which has been standardized by the 3rd generation partnership project (3GPP)[1], is a promising technique and has been commercially deployed in USA and Korea. Orthogonal frequency division multiple access (OFDMA) is adopted in LTE as the downlink access scheme owing to its high spectrum efficiency and robustness[2]. In broadband wireless communications, due to the broader bandwidth requirement, LTE will use higher carrier frequency than 3G & 2G, which results in smaller cells, or more cells needed to cover the same area. The broadband orthogonal frequency and code division multiplexing (OFCDM) system with two-dimensional (2-D) spreading was investigated to further enhance the peak data rate[3-4]. Thus, operating expenditure (OPEX) increases enormously. Moreover, key procedures in LTE cellular systems, e.g., handover (HO), are more frequent and complex. A seamless handover algorithm, which employs a train relay station, was proposed to decrease the handover failure probability[5]. Manual setting of handover parameters is extremely time-consuming and man-made mistakes are unavoidable. Therefore, new schemes are required to operate cellular systems.

Self-organizing network (SON) was introduced in 3GPP to adjust the key parameters automatically[6-7]. The main functions of SON include self establishment of new evolved Node B (eNB), adjacent cell list updating, load balancing (LB), cell outage compensation, and so on[8-9]. This paper focuses on two essential functions,

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i.e., mobility LB (MLB) and HO parameter optimization (HPO). LB is defined as an automatic scheme to cope with the unequal traffic load among neighboring cells, so that the transmission efficiency can be improved across the whole network. HPO aims to minimize HO failure ratio and guarantee the continuous services for users.

LB and HPO have been widely studied. LB is achieved based on the cell breathing technique. Novel power control algorithms were proposed in [10-11], which reduce (or rise) the power level to contract (or expand) the coverage of congested (or under-loaded) cells. Another method is to control the beam coverage pattern of "common signals", so that the sizes and shapes of cells can be automatically adjusted to balance the serving cell load[12]. Moreover, a traditional HO approach was presented to achieve load balancing, which chooses the cell with the heaviest physical resource block (PRB) burden as the source cell, and the adjacent cell with the smallest PRBs occupation as the target cell[13]. Meanwhile, theoretical analysis was carried out for LB, considering a formulation of network-wide proportional fairness (PF) in a multiple cells scenario[14]. Radio resource management (RRM) optimization was also introduced in SON. In [15], the cell-specific offset is adjusted automatically based on the source cell and neighboring cells payloads. A novel two-layer MLB (TL-MLB) algorithm was presented in [16], where the over-load cell can choose target cell from the two-layer surrounding cells. LB was co-optimized with some other parameters in cellular networks. The authors in [17] jointly investigated LB and network load minimization in LTE multi-cell scenarios. In addition, partial frequency reuse strategy and LB schemes were jointly optimized in [18], which provides an online algorithm consisting of inter and intra cell handover mechanisms for serving users and new arriving users.

Recently, lots of attentions have been received for HPO schemes. Compared with the parameter setting for the soft HO usually used in conventional code division multiple access (CDMA) systems, the parameter setting for the hard HO adopted in LTE is more sensitive to the RRM schemes[19-21]. HO failure ratio and Ping-Pong HO ratio were co-optimized for high speed users[19-20]. However, time-varying effect, e.g., velocity and moving direction, was not considered. The authors in [21] proposed a novel HO parameter optimization algorithm, which does not require additional UE mobility estimation, to overcome the channel fast fading. The simulation results in [21] showed that HO failure ratio and Ping-Pong HO ratio were reduced significantly.

Above mentioned literatures do not jointly consider LB and HPO optimization. Actually, these two techniques both can be applied to improve the network performance by adjusting HO parameters. However, the requirements of LB and HPO may have some conflicts in some scenarios[22], where MLB is allowed to have higher priority compared with HPO. As a result, the success ratio of HPO will be decreased. Furthermore, this scheme needs to modify 3GPP specifications, which declare that the QoS for users in the LB cells should have higher priority compared with users in the non-balancing cells. In this paper, we aim at looking for a novel algorithm to achieve better trade-off between LB and HPO for the LTE SON systems.

In this paper, we present a dynamic adjusting algorithm named as CSF (Co-Satisfaction Factor) to jointly optimize MLB and HPO performance. Firstly, we limit the maximum radio link failure (RLF) ratio to a constant value according to the network operators' requirement. Secondly, we propose CSF which can improve both RLF and user satisfaction. Then, the proposed CSF algorithm is optimized. Finally, the analysis of the simulation results is given to exhibit the advantages of the proposed algorithm.

2 System Model

2.1 Scenario Description

An LTE system consists of an evolved packet core (EPC), several eNBs and lots of user equipments (UEs). EPC and eNB exchange messages via S1 interface, while X2 interface provides the signaling pipe between eNBs. As depicted in Fig.1, a regular N-hexagonal cells topology is considered in this paper. eNBs are deployed at the cell center. Without loss of generality, all the users are assumed to have the same data rate requirement.

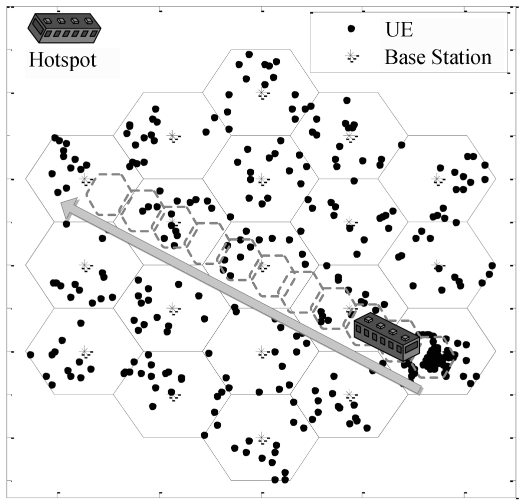

Fig.1. Regular 19-hexagonal cells layout with an inter site distance of 1000 m.

The serving users are divided into two groups. One contains background users, who are randomly positioned in the topology. The other consists of hotspot users, who are always gathered at the same spot. These users move throughout the N cells when the simulation is carried out, and the path trace is indicated in Fig.1. The signal to noise and interference ratio for the u-th user is given by

$$\lambda_u = \frac{P \times PL_{X(u),u}}{\sigma^2 + \sum_{c=1|c\neq X(u)}^{N} L_c \times P \times PL_{c,u}}, \quad (1)$$

where P is the transmit power of the eNB at each cell. $X(u)$ represents the serving eNB ID for the user u, and $PL_{c,u}$ is the overall attenuation between the eNB of cell c and user u, which contains the impact of path loss, shadow fading and antenna gain. σ^2 is the addictive white Gaussian noise, and L_c is the load of the cell c. After deriving SINR from (1), the achievable data rate can be obtained as $R(\lambda_u)$. Assume that the constant-bit-rate (CBR) D_u equals 0.5 Mbps, so the amount of resources required by the user u can be expressed as

$$N_u = \frac{D_u}{R(\lambda_u)}.$$

Given the fixed CBR traffic, the UEs either get exactly the CBR or they are totally unsatisfied. Thus, the number of unsatisfied users is employed as a performance criterion in this paper. A virtual load $\overline{L_c}$ is defined as

$$\overline{L_c} = \frac{\sum_{u|X(u)=c} N_u}{N_{\mathrm{tot}}},$$

where $u|X(u) = c$ represents the user ID in the cell c, and N_{tot} is the total number of physical resource blocks. It can be seen that if $\overline{L_c} \leqslant 1$, all users in the cell are satisfied. However, if $\overline{L_c} = 3$, it means only 1/3 of the users can be satisfied. The cell load is defined as the physical resource blocks required by all serving users divided by N_{tot}, which is given by

$$L_c = \min(\overline{L_c}, 1).$$

The number of unsatisfied users in the whole network can be written as

$$Z = \sum_{c=1}^{N} \max(0, M_c \times \Big(1 - \frac{1}{\overline{L_c}})\Big),$$

where M_c is the number of users in the cell c.

For performance analysis, we define a load distribution index which is similar to the Jain's fairness index to measure the degree of load balancing of the entire network[24], which is given by

$$\nabla(t) = \frac{\Big(\sum_{c=1}^{N} L_c(t)\Big)^2}{N \times \sum_{c=1}^{N} (L_c(t))^2},$$

where ∇ is the load distribution index, and t is the time. The load distribution index ∇ is 1 when the cell load is completely balanced among cells. The smaller the value of ∇ is, the worse the unbalanced load distribution among cells is. Therefore, the target of LB is to maximize the parameter ∇.

2.2 Performance Indicators

The major HO performance indicators (HPI) of HPO include the times of HOs which are initiated but not completed (HO failures), repeated back and forth HOs between two base stations ("Ping-Pong" HOs), and the RLF due to unsuccessful HO[23].

However, Ping-Pong HO only increases the HO times without losing the user's connection, while HO failure is not so fatal as RLF because it still allows the users to be linked with their previous eNBs. Only RLF would cause the call drop and make the user service interrupted. So RLF ratio is usually regarded as the most important indicator in HPI. In practical networks, the allowed maximum RLF ratio is usually limited to a constant value γ, which is equal to 10%. If RLF ratio is higher than γ, lots of call drops will be introduced. So the most important indicator RLF ratio and its limitation will be taken as the performance criterion in the analysis and simulation of HPO.

According to 3GPP[25], an RLF procedure is described in Fig.2. Once control signaling or data cannot be delivered to the eNB, in other words, the uplink block error ratio is larger than the uplink received threshold Q_{out}, this link is observed as the asynchronous link at the eNB. At this moment, the $T1$ timer is started. If the uplink block error ratio is small than Q_{in} before $T1$ is expired, the uplink data transmission is recovered. However, if the eNB and the UE are still asynchronous, the RLF procedure is triggered by the eNB and meanwhile the $T2$ timer is started. The uplink transmission is resumed to the connection mode when the eNB and UE are asynchronous before $T2$ is expired. However, in case the UE experiences the long deep fading or is located at the cell edge, the eNB will re-allocate the physical resource after $T2$ is expired, and this UE needs to fall back to the idle mode. The exact values of $T1$ and $T2$ are selected based on the system

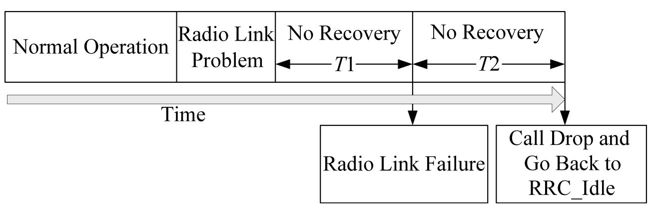

Fig.2. Radio link failure.

performance criterion. In the practical system, Q_{out} is usually equal to 10% and Q_{in} is set to 2%.

3 LB and HO Parameter Optimization

An HO event is initiated when the UE detects that a neighboring cell offers a better signal quality than its currently serving cell. This condition is simplified by just concerning intra/inter-frequency handover, and it is referred to as event $A3$[2], which is formulated as

$$M_t + O_t > M_s + O_s + OS_{s,t} + H_{s,t}, \quad (2)$$

where M_s and M_t are the signal power for serving cell s and target cell t, respectively. M_t and M_s are expressed in dBm in case of reference signal received power (RSRP), or in dB in case of reference signal received quality (RSRQ). $H_{s,t}$ is the hysteresis parameter for handover event from the cell s to the cell t. $OS_{s,t}$ is the offset parameter for the HO event from the cell s to the cell t. O_t and O_s represent the serving and target cell specific offset, respectively, which are pre-set to be zero if not configured.

As can be seen from (2), when $OS_{s,t}$ is small, it is easy for UEs to camp on the cell s rather than to migrate to the cell t. LB is performed by automatically adjusting $OS_{s,t}$ based on cell load measurements. Meanwhile, HPO is applied to adjust the HO parameter according to the HPI.

HPO and LB operate independently, but they are closely related to each other because the two functions adjust coupled handover parameters to optimize network parameters. LB copes with the unequal traffic load between cells by adjusting $OS_{s,t}$. HPO minimizes handover failure through adjusting $H_{s,t}$. Conflict may occur when they adjust these parameters without coordination.

When an overload cell is reported, LB function adjusts the $OS_{s,t}$ of adjacent target eNB (TeNB). Thus the cell coverage range is changed. Some users would be out of the overloaded source eNB (SeNB) and forced to handover to TeNB. Then the number of handover inevitably increases and the radio link fails, the HO failure and Ping-Pong HO may also increase. In this case, the HPO algorithm might be triggered to adjust $H_{s,t}$, which is in contradiction to the aim of LB and may cause Ping-Pong HO of the users previously handed over. For better understanding, the interaction between LB & HPO is presented in Fig.3.

It can be seen that when LB decreases the cell radius to reduce the overload, the radio link is deteriorated and HOs increases significantly. Note that the parameter γ is the allowed biggest RLF ratio according to the need of the network operator. And α is set below γ in our algorithm. If the RLF ratio is higher than α, the operator should pay more attention to the network handover performance to prevent the RLF ratio from reaching γ, e.g., stopping or restraining LB. On the other hand, when the RLF ratio is below α, LB and HPO can be executed simultaneously.

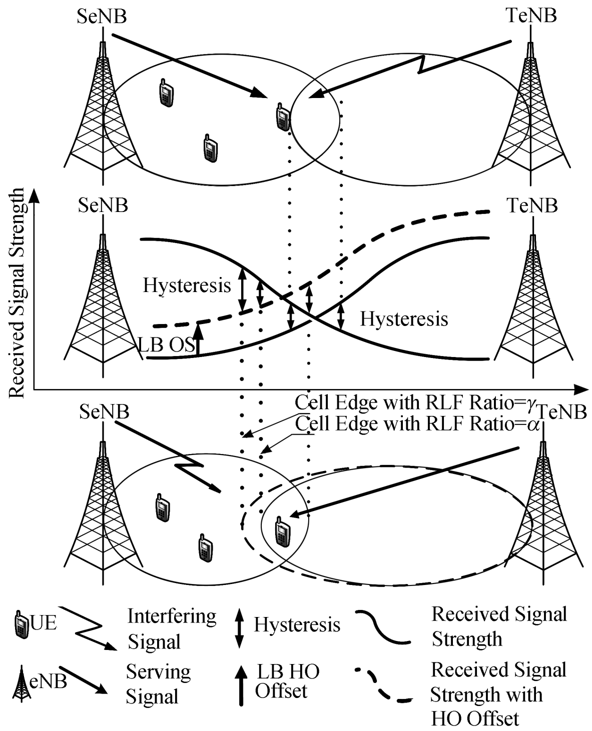

Fig.3. Interaction between LB and HPO.

As introduced before, LB and HPO both have strategies to maximize their own benefit independently. To measure the performance of LB and HPO jointly, CSF is defined by using linear weighted sum method[26-27] to indicate a trade-off between LB and HPO, which is given by

$$R_{\text{CSF}} = w_1 \times R_{hs} + w_2 \times R_{us}, \quad (3)$$

where R_{hs} is HO success ratio, and R_{us} is the user satisfaction ratio, which is defined as the number of satisfied users divided by the number of total users. w_1 and w_2 are the weighting factors for R_{hs} and R_{us}, respectively, which are set based on the requirement of network operators. For example, if R_{hs} is more important to network operators, then maybe a weight set of (0.8, 0.2) is chosen. R_{hs} is equal to the number of success HOs(N_{HOsucc}) divided by the sum of N_{HOsucc} and failed HOs(N_{HOfail}), which is given by

$$R_{hs} = \frac{N_{\text{HOsucc}}}{N_{\text{HOsucc}} + N_{\text{HOfail}}}.$$

A small value of R_{hs} indicates that the RLF ratio is high while should not exceed γ. Low R_{us} represents that a large number of users are not satisfied, which is caused by the heavy load in cells. Therefore a threshold β is introduced. When the cell load is larger than β, more attention should be paid to the LB.

Targeting at maximizing $R_{\rm CSF}$, the dynamic adjusting method is described as below:

• If the RLF ratio is larger than α, $OS_{\rm s,t}$ and $H_{s,t}$ should be jointly adjusted to carry out HPO as well as restrain LB to satisfy the network requirement. The detailed adjustment of $H_{s,t}$ is discussed in [28]. If the cell load is larger than β, $OS_{s,t}$ should be adjusted to enhance LB and improve $R_{\rm CSF}$ at the same time. $OS_{s,t}$ will be adjusted as follows:

$$OS_{s,t} = \min\Big(\max\Big(\Delta \times \frac{L_s - L_t}{L_t}, -OS_{\max}\Big), OS_{\max}\Big), \tag{4}$$

where Δ is the offset step-size and L_s and L_t are the load of the source and the target cell, respectively. $OS_{\max}$ and $-OS_{\max}$ are the upper and lower bound of $OS_{s,t}$ respectively. $OS_{s,t}$ is initiated to zero and updated according to (4) in each LB loop, in response to new load measurements reports for each cell. Equation (2) indicates that the increasing of $OS_{s,t}$ would make load shift from source cell to target cell easier, so the adjusting of $OS_{s,t}$ would undoubtedly decrease the difference between L_s and L_t, therefore, realize load balancing and enhance user satisfaction ratio.

If the RLF ratio is smaller than α and the cell load is smaller than β, the combination of $OS_{s,t}$ and $H_{s,t}$ that maximize (3) would be searched. If the adjustment improves R_{hs} and R_{us} at the same time, then the same direction would be followed in next period; if the adjustment decreases both R_{hs} and R_{us}, CSF would averse the adjusting direction; if one of R_{hs} and R_{us} is increasing while the other one is decreasing, $R_{\rm CSF}$ will act as a guide to ensure that the overall co-satisfaction rate is increasing.

Another phenomenon is that actions of one function may also intensify the effects of the second function. When HPO algorithm allows some users to HO by reducing the hysteresis in the direction that is desired by the LB algorithm as well, this HPO action will intensify the effects of LB. Actually, if the adjust of $H_{s,t}$ in HPO corresponds with (5), such adjust in HPO will intensify the effects of LB.

$$H_{s,t}(i) = \begin{cases} H_{s,t}(i-1) + \eta, & \text{if case a,} \\ H_{s,t}(i-1) - \eta, & \text{if case b,} \end{cases} \tag{5}$$

where case a represents the situation that the target cell t has more load than the source cell s, and case b represents the situation that the target cell t has less load than the source cell s. η is the adjustment of $H_{s,t}$ in HPO. The CSF algorithm is shown in Fig.4.

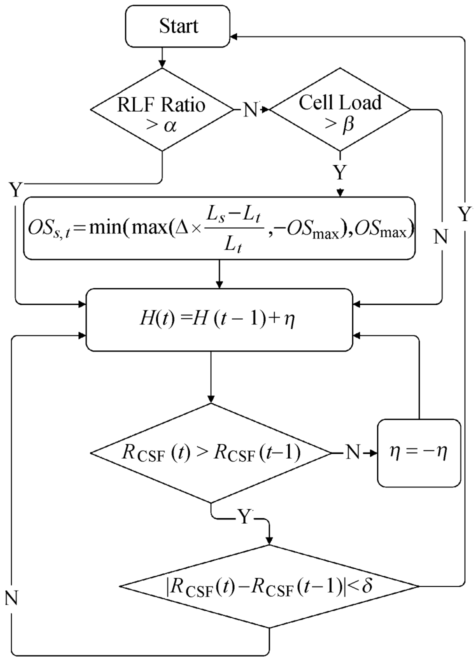

Fig.4. Flow chart of CSF.

When the RLF ratio is larger than α, H is adjusted, and η is the adjustment of $H_{s,t}$ in HPO. After the adjustment, if $R_{\rm RLF}(t) > R_{\rm RLF}(t-1)$, where $R_{\rm RLF}(t)$ represents the RLF ratio at the time t, η turns into its opposite number and H is adjusted until $R_{\rm RLF}(t) < R_{\rm RLF}(t-1)$. Then we compare $|R_{\rm CSF}(t) - R_{\rm CSF}(t-1)|$ and δ, which is the CSF threshold. When the RLF ratio is smaller than α and the cell load is larger than β, $OS_{s,t}$ is adjusted according to (4), then H is adjusted similarly as previous. When the RLF ratio is smaller than α and the cell load is smaller than β, $H_{s,t}$ is adjusted similarly as previous.

4 Simulation

In this section, system level simulations for the LTE cellular network are carried out to evaluate the performance of the proposed algorithm. The simulation platform contains 19 regular hexagonal cells, and the cell radius is 577m. In order to avoid boundary effects, the wrap around technique is applied. For simplicity, only one eNB is located in the cell center, and there is no sectors. Fifteen background users are uniformly dropped per cell, while the hotspot (i.e., a moving bus) contains 50 users. Without loss of generality, it is assumed that the maximum number of serving users in each cell is 30. If more than 30 users are simultaneously positioned in a specific cell, overload occurs. The constant target date rate for each user is 0.5 Mbps. The total simulation period is set to 20 minutes to average the time varying characteristic. During the simulation, the optimization update periods of LB and HPO are 1 s and 30 s, respectively. Detailed simulation assumptions and parameters are give in Table 1.

Table 1. Simulation Parameters

Parameter	Assumption
Path loss	$-38.4 - 35.0 \lg R$
Shadow fading (SF)	Log-normal
SF correlation distance	10 m
Antenna gain	−7 dB
Number of Tx antenna	1
Number of Rx antenna	2
UE velocity	30 km/h

Fig.5 depicts the user satisfaction (US) ratio for three schemes. The first algorithm does not consider HPO and LB (NO HPO or LB). The second one adopts HPO and LB without coordinate (HPO + LB). The third one is CSF. In the simulations, the users in the hotspot are moving across the topology through a predefined trail. When the hotspot is moving into the cell, unsatisfied users will appear, because the number of total users in the current cell is larger than 30. As shown in Fig.5, the US ratio decreases to a low point after the hotspot moves to the center (i.e., the 150th second, 660th second) because those users are difficult to execute handover. It can be observed that the US ratio for HPO+LB is similar to that of CSF, and both schemes enhance the US ratio significantly. The US ratio for NO HPO or LB is the least nearly all the time. This is because excessive users in the overload cell have not switched to adjacent cells for LB and the overload cell cannot give service to so many users. Between the 700th second and the 900th second in Fig.5, the US ratio for CSF is less than that of HPO+LB. This is because many users are switched to adjacent cells in the HPO+LB scheme while some users' handovers are restricted to ensure the handover performance in CSF. But if the signals of the adjacent cells are not very good, a large amount of handovers cause failed handover (as shown in Fig.6.).

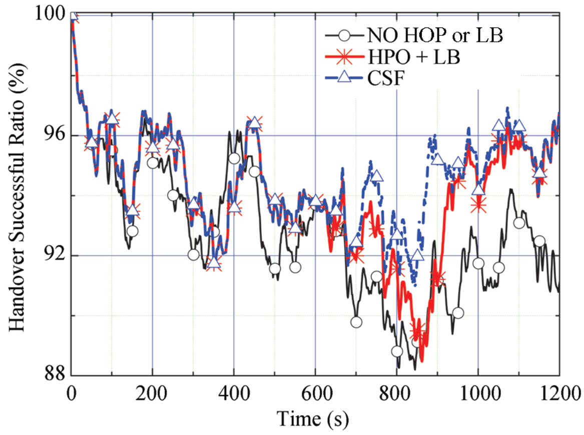

Fig.6. Handover successful ratio.

The performance of HO success (HS) ratio is shown in Fig.6. Different to the HPO+LB scheme, CSF will adaptively adjust the parameters, if the RLF ratio is higher than 8%. As shown in Fig.5 and Fig.6, the proposed CSF scheme can achieve better trade-off between HOP and LB, i.e., between the 700th second and 900th second, and the US ratio is slightly sacrificed while the handover successful ratio is guaranteed to be larger than 91%.

Co-satisfaction ratio is shown in Fig.7. It can be seen that the proposed CSF scheme outperforms the other two schemes. The reason is that CSF scheme always adjust OS and optimize the co-satisfaction factor to improve both HPO and LB performance. If the

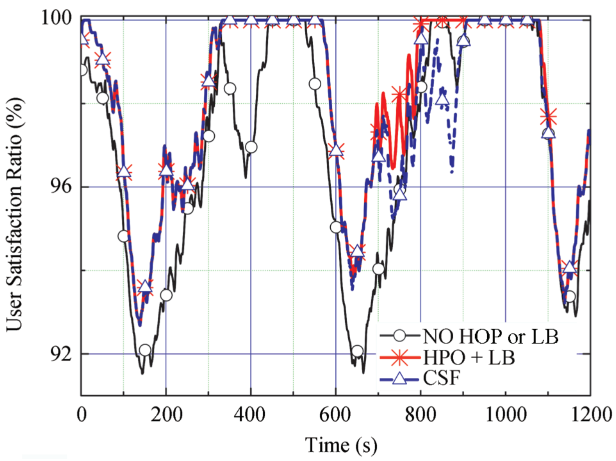

Fig.5. User satisfaction ratio.

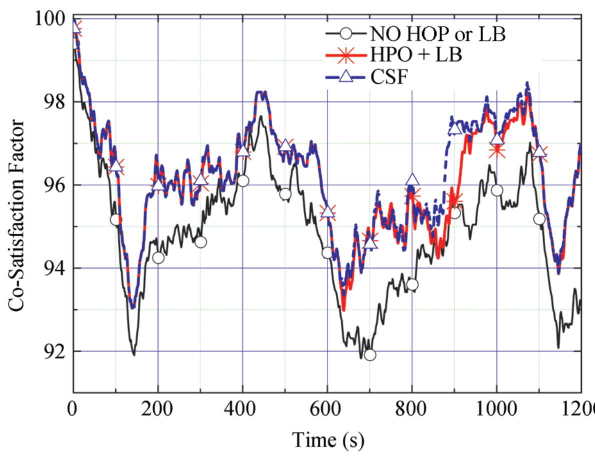

Fig.7. Co-satisfaction ratio.

adjustment is unhelpful or impairs the network co-satisfaction ratio, the proposed scheme would change the direction of optimization to maximize the network gain. From the 700th second to the 1000th second, the US ratio is slightly sacrificed while the handover successful ratio is largely promoted, so the co-satisfaction ratio is improved.

Fig.8 shows the RLF ratio of the three schemes. It is shown that the RLF ratio of the HPO+LB scheme is higher than 10% in 12% simulation duration (about 140 seconds), which is not tolerated in practical networks. The CSF scheme achieves much better radio link performance, which always keeps the RLF ratio lower than 9%.

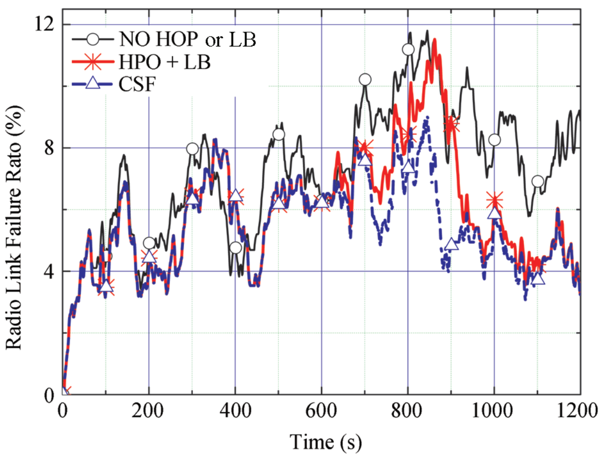

Fig.8. Radio link failure ratio.

5 Conclusions

In this paper, a novel scheme named as CSF was proposed to achieve a better trade-off between LB and HPO. In the scheme, a co-satisfaction indicator (R_{CSF}) is introduced which contains the impact of handover success ratio and user satisfaction ratio (R_{us}). Different from previous investigation, where LB and HPO only focus on their own benefit, which leads to the conflict between these two SON functions, the CSF scheme was carefully designed to enhance both LB and HPO performance. System level simulation was carried out to evaluate the proposed scheme. The results show that the proposed CSF scheme provides much better performance in terms of network HO success ratio and user satisfaction ratio than the other two schemes.

In the future, we will check the proposed CSF algorithm in practical systems to further verify the performance enhancement.

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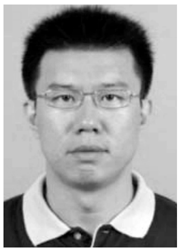

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