Mobility Load Balancing Scheme based on Cell Reselection

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***Abstract*—Mobility Load Balancing (MLB) is one of the most important functions of Self-Organizing Networks (SON) in Long Term Evolution (LTE). The conventional MLB schemes based on handover (HO) conflict with Mobility Robustness Optimization (MRO) because both operations adjust the same HO parameters. The simulation results show that the conventional MLB scheme cannot achieve load balancing gain without some degradation in HO performance. In order to solve the conflict problem, this paper proposes an MLB scheme based on cell reselection (CR) that works in coordination with MRO. The proposed scheme adjusts the CR parameters and not the HO parameters, and never conflicts with MRO. Through computer simulations, it is shown that the proposed scheme can realize effective load balancing on a par with conventional schemes without any degradation in HO performance. The simulation results show that the proposed scheme is especially effective in an environment where a lot of small-size data packets are transmitted by a large number of users, which is highly applicable to current mobile networks with explosive diffusion of smart phones. In such case, more than 10% and 90% gains can be obtained in the total throughput and 5th percentile user throughput, respectively.**

Keywords: LTE; self-organizing networks (SON); mobility load balancing (MLB); mobility robustness optimization (MRO); cell reselection

I. INTRODUCTION

In conventional cellular networks, system parameters are manually adjusted to maintain and/or improve the operational performance. However, due to the rapid evolution of networks, the parameters have become more complex and larger, and such manual tuning of the parameters is becoming increasingly difficult. In order to reduce the operational complexity of cellular networks, the concept of Self-Organizing Networks (SON) has been introduced into Long Term Evolution (LTE) and is currently being discussed in the 3rd Generation Partnership Project (3GPP) [1].

One of the main functions of SON is Mobility Load Balancing (MLB) [2]. In cellular networks, traffic demand dynamically changes both in time and space, and it is common for some cells to be heavily loaded, whereas their adjacent cells are not. The objective of MLB is to distribute cell load evenly among adjacent cells or to transfer part of the traffic from congested cells. In MLB, this is done by self-optimization of the mobility parameters.

In the 3GPP, the concept, requirements, procedures and interfaces of MLB are discussed. The actual solutions are left to vendor specific algorithms and several algorithms for the optimization of the mobility parameters have been reported in the literature [3][4][5][6][7][8][9][10][11]. They considered MLB based on handover (HO), which is referred to as "HO-MLB" hereafter. HO-MLB adjusts the HO timing by biasing the HO measurements, forcing user equipments (UEs) around the cell-edge in highly loaded cells to hand off to less loaded neighboring cells in order to share traffic between adjacent cells. The unavoidable problem in any attempt to realize HO-MLB is the conflict with Mobility Robustness Optimization (MRO), which is also one of the important functions of SON [2]. MRO aims to minimize HO failures and reduce ping-pong HOs by adjusting the HO parameters. Therefore, it is possible that both HO-MLB and MRO adjust the same HO parameter in the opposite directions at the same time and the conflict may lead to performance degradation. The conflict problem between HO-MLB and MRO was investigated in detail [6]. In [6], the authors proposed a solution to avoid the conflict problem by imposing a restriction on HO-MLB through setting an allowed range to make sure that HO failures never occur. However, the proposal is not a sufficient solution because the load balancing is extremely limited by the operation of MRO and the gain is therefore expected to be negligible. Moreover, it is very difficult to determine the allowed range for in-service cellular networks where the allowed range varies dynamically in response to changes in the radio environment and UE mobility. In such networks, the scheme may not work effectively.

Cell reselection (CR) also has the potential to realize load balancing [2]. We refer to an MLB based on CR as "CR-MLB" hereafter. In the same way as HO-MLB, the adjustment of the CR timing by biasing the CR measurements causes the UEs around the cell-edge in highly loaded cells to migrate to less loaded neighboring cells. While HO-MLB is intended for UEs in radio resource control (RRC) connected mode, CR-MLB is intended for UEs in RRC idle mode. In previous studies of MLB, HO-MLB is mainly studied because the adjustment of CR parameters is only effective during call set-up and the optimization of HO parameters is considered to be the preferred option [9]. However, CR-MLB has a great advantage over HO-MLB in that there is no conflict with MRO because CR-MLB and MRO adjust different parameters. Therefore, CR-MLB can be a promising way to realize load balancing more than HO-MLB. To the best of our knowledge, the performances of CR-MLB have not been reported.

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In this paper, we propose a CR-MLB scheme that works in coordination with MRO. The proposed scheme adjusts CR parameters under the restriction determined by the HO parameters, which are obtained by MRO operating independently of MLB. The proposed scheme is expected to realize load balancing without any degradation in HO performance. In order to examine the performance and clarify the applicable scope of the proposed scheme, we perform the computer simulations over different UE distributions and traffic patterns.

The rest of the paper is organized as follows. In section II, we explain the conventional HO-MLB scheme, and the influence on HO performance is clarified through a computer simulation. Section III introduces the proposed CR-MLB scheme. The performance of the proposed scheme is evaluated in section IV. Finally, we conclude this paper in section V.

II. Mobility Load Balancing Based on Handover

In this section, we introduce the HO procedure in 3GPP LTE and then explain the operational principle of the conventional MLB scheme based on the HO (HO-MLB). The influence of HO-MLB on HO performances is also examined by computer simulations.

A. HO Procedure

The HO procedure in 3GPP LTE begins with measurement report (MR) transmission from a UE to its source cell (serving cell). The UE periodically performs downlink channel measurements based on cell-specific reference signals and checks whether the signal strengths satisfy the conditions for MR transmission. The entering condition for event A3, which is one of the MR triggering events generally used for the HO procedure [12], is defined as

$$M_1 - M_0 > Hys_0 + a3Offset_0 - CIO_{0,1}, \qquad (1)$$

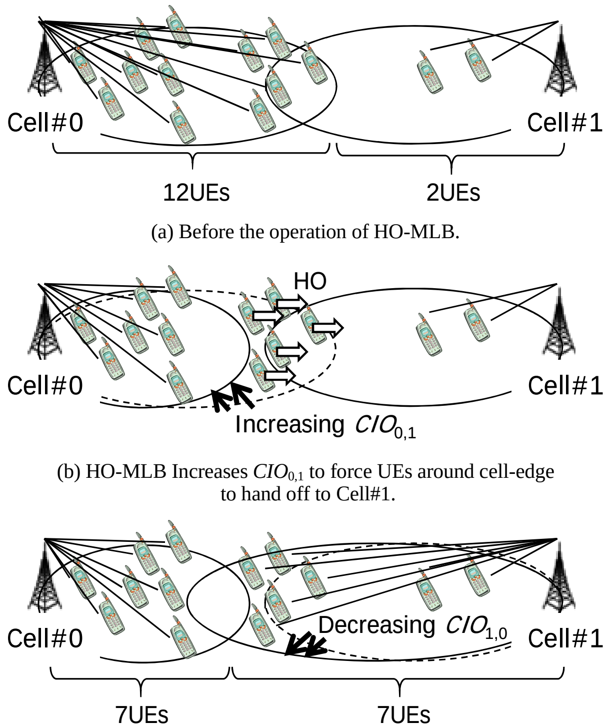
where M_0 and M_1 are the signal strengths of the serving cell (Cell#0) and the target cell (Cell#1), respectively. Hys_0 is the hysteresis parameter and $a3Offset_0$ is the offset parameter for event A3. In order to simplify the discussion without generality, we disregard Hys_0 and $a3Offset_0$ in this paper. By substituting $Hys_0 = a3Offset_0 = 0$ into (1), we obtain the following condition;

$$M_1 - M_0 > -CIO_{0,1}, \qquad (2)$$

where $CIO_{0,1}$ is a cell-specific offset parameter set by Cell#0 for Cell#1 and is called “Cell Individual Offset (CIO).” If condition (2) is satisfied for duration of Time To Trigger (TTT), the UE sends the MR to Cell#0 and the HO procedure from Cell#0 to Cell#1 is initiated.

B. Conventional HO-MLB Scheme

The operational principle of HO-MLB is illustrated in Figure 1. As shown in Figure 1(a), 12 UEs and 2 UEs belong to Cell#0 and Cell#1, respectively, that is, Cell#0 is more loaded than Cell#1. In this case, as illustrated in Figure 1(b), the HO-MLB scheme increases $CIO_{0,1}$ to make the HO timing from Cell#0 to Cell#1 earlier and UEs of Cell#0 near Cell#1 will hand off to Cell#1. In addition, as shown in Figure 1(c), the HO-MLB scheme can decrease $CIO_{1,0}$ to make the HO timing from Cell#1 to Cell#0 later in order to keep the handed off UEs from Cell#0 staying in Cell#1. Finally, the load is shared equally between Cell#0 and Cell#1.



(a) Before the operation of HO-MLB.

(b) HO-MLB Increases $CIO_{0,1}$ to force UEs around cell-edge to hand off to Cell#1.

(c) HO-MLB decreases $CIO_{1,0}$ to keep UEs around the cell-edge staying in Cell#1.

Figure 1. Operational principle of HO-MLB.

C. Influence on HO pereformances

The adjustment of the HO timing by the HO-MLB scheme may cause performance degradation of HO processes. Here the influence of HO-MLB on HO performances is examined through computer simulations. We evaluate the HO failure rate and ping-pong HO rate between Cell#0 and Cell#1 by changing $CIO_{0,1}$ and $CIO_{1,0}$. In the simulations, the number of HO failures is counted if “Too Late HO,” “Too Early HO,” or “HO to Wrong Cell” is observed [2]. The number of ping-pong HOs is counted when the UE returns to the original serving cell within a pre-determined minimum-time-of-stay (MTS) after a HO from the original serving cell to a neighboring cell [13] and the MTS value in the simulations is set to 2 seconds. The HO failure rate and ping-pong HO rate is defined as the ratio of the number of HO failures and ping-pong HOs divided by the number of all HOs including HO failures, respectively. The other simulation conditions are summarized in Table I.

In order to obtain significant load balancing gain, the MLB scheme should be operated in an environment in which low mobility UEs are dominant. Therefore, we assume that UE mobility is 3 km/h throughout the paper. In the case of 3 km/h, we run the MRO [14] and find that the optimal CIO value that minimizes the sum of the HO failure rate and ping-pong HO rate is –6 dB. The default CIO value is set to –6 dB.

TABLE I. SIMULATION CONDITIONS

Inter-Site Distance	500 m
eNB Power	43 dBm
Pathloss	120.9+37.6 $\log_{10}$(d)
Shadowing	Standard deviation: 8 dB, Correlation distance: 50 m
Fading	Typical Urban 6path
UE Mobility	Uniform Distribution, Random Walk, 3/30/60/120/240 km/h
L3 Filter Parameter	*K*: 4
Handover	T300: 1 s, T301: 500 ms, T304: 400 ms, T311: 10 s, delay (X2): 60 ms, delay (intra-eNB): 10 ms, Tstore_ue_context: 1 s, Time to Trigger: 256 ms
RLF Detection	Qin: –6 dB, Qout: –8 dB, N310: 1, N311: 1, T310: 1 s

Figure 2 shows the HO failure rate and ping-pong HO rate when the HO-MLB scheme increases $CIO_{0,1}$ from the default value of –6 dB to 6 dB while $CIO_{1,0}$ is fixed to –6 dB. It is found that the HO failure rate is almost zero for all CIO values, but the ping-pong HO rate becomes higher as the HO-MLB scheme increases $CIO_{0,1}$. This is because the hysteresis region becomes narrower by increasing $CIO_{0,1}$. It is undesirable for the incidence of ping-pong HO to be too high as it consumes a lot of radio resources as well as placing an unnecessary burden on the hardware units of eNBs and wastes backhaul resources. If we introduce a policy whereby the ping-pong HO rate is kept below 15 %, HO-MLB can increase $CIO_{0,1}$ only up to –2 dB and this may result in little load balancing gain being achieved. The gain will be evaluated in detail in section IV.

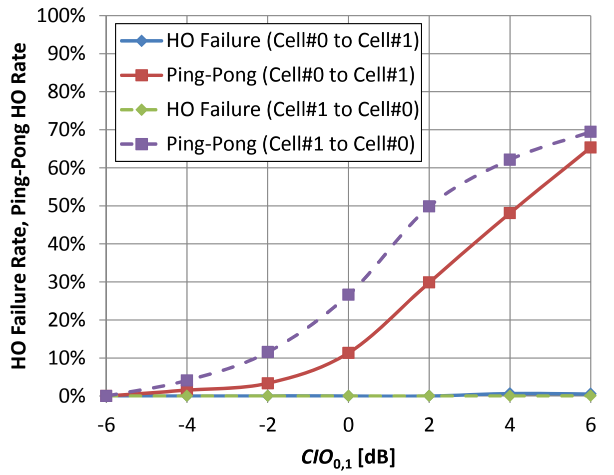


Figure 2. HO failure rate and ping-pong HO rate: $CIO_{0,1}$ is changed from –6 dB to 6 dB, while $CIO_{1,0}$ is the fixed value of –6 dB.

In order to prevent ping-pong HO from occurring, HO-MLB has to keep the hysteresis region at 12 dB by decreasing $CIO_{1,0}$ according to the increase in $CIO_{0,1}$ as shown in Figure 1(c). Figure 3 shows that decreasing $CIO_{1,0}$ causes a large number of Too Late HO from Cell#1 to Cell#0 and the HO failure rate becomes critically high as HO-MLB increases $CIO_{0,1}$. It is found that the increase in HO failures is inevitable when HO-MLB decreases $CIO_{1,0}$. As a result, this option is not an appropriate approach because the HO failures directly influence the user performance.

Finally, from Figures 2 and 3, it can be concluded that HO-MLB cannot achieve load balancing gain without some degradation in HO performance.

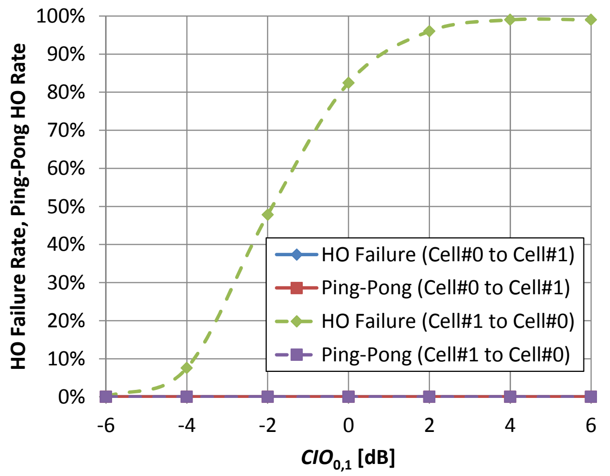


Figure 3. HO failure rate and ping-pong HO rate: $CIO_{0,1}$ is changed from –6 dB to 6 dB and $CIO_{1,0}$ is changed so that the hysteresis region is kept at 12 dB. For example, $CIO_{1,0}$ is set to –6 dB and –18 dB when $CIO_{0,1}$ is set to –6 dB and 6 dB, respectively.

III. MOBILITY LOAD BALANCING BASED ON CELL RESELECTION

In this section, we introduce the CR procedure in 3GPP LTE and then explain the operational principle of the proposed MLB scheme based on the CR (CR-MLB).

A. *Cell Reselection Procedure*

The CR procedure in 3GPP LTE is performed as follows. The UE in RRC idle mode periodically performs idle mode measurements. When more than 1 second has elapsed since the UE camped on the current serving cell and the following condition (3) is satisfied during a time interval of $Treselection_{RAT}$, the UE camped on Cell#0 shall perform cell reselection to Cell#1 [15].

$$M_1 - M_0 > Q_{Hyst,0} + Qoffset_{0,1}, \qquad (3)$$

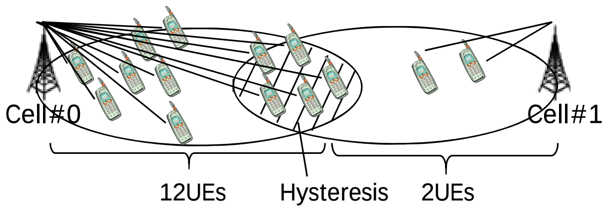
where M_0 and M_1 are the signal strengths of the camped cell (Cell#0) and the target cell (Cell#1), respectively. $Q_{Hyst,0}$ is the hysteresis parameter and, to simplify the discussion, we disregard it in this paper. By substituting $Q_{Hyst,0} = 0$ into (3), we obtain the following condition;

$$M_1 - M_0 > Qoffset_{0,1}, \quad (4)$$

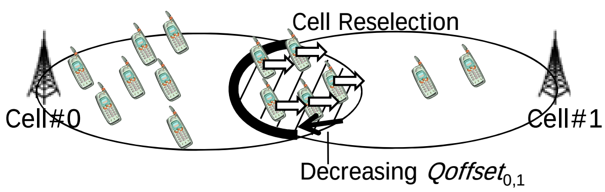
where $Qoffset_{0,1}$ is a cell-specific offset parameter set by Cell#0 for Cell#1 called Qoffset. In normal operation, the CR timing is adjusted to be the same as the HO timing and then $Qoffset_{0,1}$ is equal to $-CIO_{0,1}$.

B. *Proposed CR-MLB Scheme*

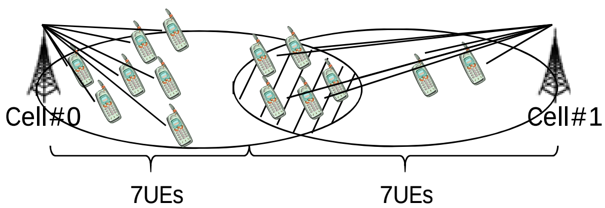
Figure 4 illustrates the operational principle of CR-MLB. As illustrated in Figure 4(a), 12 UEs and 2 UEs in RRC connected mode belong to Cell#0 and Cell#1, respectively. Because Cell#0 is more loaded than Cell#1, the CR-MLB scheme decreases $Qoffset_{0,1}$ to make the CR timing from Cell#0 to Cell#1 earlier as shown in Figure 4(b). Once UEs of Cell#0 leave the RRC connected mode and enter the RRC idle mode, the UE near Cell#1 will perform cell reselection to Cell#1. Finally, as shown in Figure 4(c), the UEs camped on Cell#1 will enter the RRC connected mode and belong to Cell#1. In summary, if the UE stays within the hysteresis region of the HO parameter, it can potentially connect to both Cell#0 and Cell#1. Once the UE connects to either cell, the UE does not satisfy the HO condition and continues to stay in the same cell. CR-MLB moves such UEs to the less loaded cell when they are in the RRC idle mode.



(a) UEs in RRC connected mode before the operation of CR-MLB.



(b) CR-MLB decreases $Qoffset_{0,1}$ to force UEs in RRC idle mode around the cell-edge to perform cell reselection to Cell#1.



(c) UEs in RRC connected mode after the operation of CR-MLB.

Figure 4. Operational principle of CR-MLB.

In the proposed scheme, CR-MLB and MRO operate independently and never conflict with each other. MRO always operates and optimizes the setting of CIO to minimize the HO failure rate and ping-pong HO rate. When the traffic load in each cell is not heavy and it is not necessary to perform load balancing, CR-MLB does not operate and the CR parameter is set to the default value $Qoffset_{0,1} = -CIO_{0,1}$, which is determined by the result of MRO. If the traffic load in some cells becomes high and the traffic loads between adjacent cells are unbalanced, CR-MLB begins to operate and decreases the CR parameter of the higher loaded cell for the less loaded cells. As a result, CR-MLB works in coordination with MRO and can realize load balancing without any degradation in HO performance.

There is one concern that will need to be considered. When CR-MLB decreases $Qoffset_{0,1}$ and the hysteresis margin between the CR timing from Cell#0 to Cell#1 and the HO timing from Cell#1 to Cell#0 are close to zero, there is a high possibility for the UE performing cell reselection to Cell#1 in RRC idle mode to return to Cell#0 by HO after the UE becomes the RRC connected mode. This is because the measured signal strengths of Cell#0 and Cell#1 fluctuate over time due to the effect of fast fading, shadowing, and so on. Note that though this may reduce the load balancing gain of CR-MLB, it never causes ping-pong HO in RRC connected mode because the hysteresis of the HO parameters between $CIO_{0,1}$ and $CIO_{1,0}$ is not changed by CR-MLB. In the following section, we examine the load balancing performance of CR-MLB considering the above concern.

IV. Performance Evaluation

In this section, the load balancing performance of the proposed CR-MLB scheme is examined through computer simulations. The system-level simulator written in C++ is developed for the evaluation. First, we compare the proposed scheme with the conventional HO-MLB scheme for various offered traffic loads. We also evaluate the proposed scheme over different UE distributions and traffic patterns to clarify the applicable scope.

A. *Simulation Conditions*

Figure 5 illustrates a part of the cell layout used in the simulation. In order to examine the load balancing gain, we change CIO and Qoffset values of Cell#0 for the neighboring 6 cells (Cell#1, Cell#2, Cell#4, Cell#5, Cell#8, and Cell#19) and evaluate the downlink UE throughput in those cells.

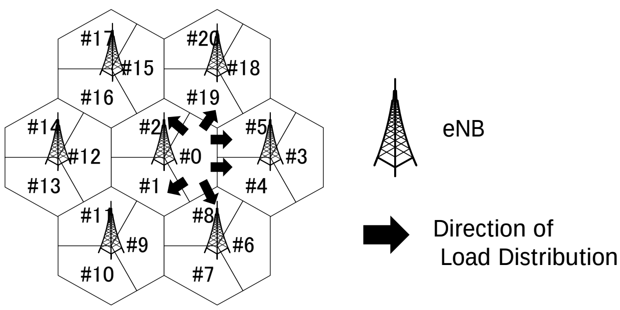


Figure 5. A part of the cell layout used in the simulation.

We define the ratio of the throughput to that for the case where $\{CIO_{0,1} = -6\text{ dB}, Qoffset_{0,1} = 6\text{ dB}\}$ as throughput gain. From the simulation results, the throughput gain for the case where $\{CIO_{0,1} = x\text{ dB}, Qoffset_{0,1} = y\text{ dB}\}$ is derived as

$$Throughput\ gain = \frac{Throughput(CIO_{0,1} = x\text{dB}, Qoffset_{0,1} = y\text{dB})}{Throughput(CIO_{0,1} = -6\text{dB}, Qoffset_{0,1} = 6\text{dB})} - 1.0, \quad (5)$$

and the gains of total throughput, 5th percentile user throughput, and 50th percentile user throughput are evaluated. As an example, throughput gain of 1.0 means that the throughput is twice as that for the case where $\{CIO_{0,1} = -6$ dB, $Qoffset_{0,1} = 6$ dB$\}$.

As for the traffic model, we assume that traffic with a fixed data size arrives at a fixed time interval per UE. Note that the timing of traffic arrival is uniformly distributed among UEs. When the traffic arrives, the UE enters the RRC connected mode and then returns to the RRC idle mode 1 second after the transmission traffic queue becomes empty. If the queue is not empty when the next traffic arrives, the UE continues to stay in the RRC connected mode. The other simulation conditions are summarized in Tables I and II.

TABLE II. SIMULATION CONDITIONS

Cell Layout	Hexagonal grid, 57 cells
Carrier Frequency	900 MHz
System Bandwidth	10 MHz
Scheduler	Round Robin
# of Antennas	TX: 1, RX: 2
# of UEs	20 UEs per Cell
Traffic Model	Traffic with a fixed data size at a fixed time interval Default data size: 475 KB Default time interval: 30 s
CIO	For Cell#0 to neighboring cells: variable For others: –6 dB
Qoffset	For Cell#0 to neighboring cells: variable For others: 6 dB
$Treselection_{RAT}$	0 s

B. Comparison with HO-MLB

First, we compare the load balancing performance of the proposed CR-MLB with that of the conventional HO-MLB schemes for various offered traffic loads. In order to compare them in the case where high throughput gain is expected to be obtained, we allocate 140 UEs to Cell#0 and no UEs to neighboring cells, that is, intentionally create an unbalanced traffic load situation between Cell#0 and the neighboring cells. In the CR-MLB, $Qoffset_{0,1}$ is changed from 6 to –6 dB and, in the HO-MLB, $CIO_{0,1}$ is changed from –6 to 6 dB.

Figure 6 shows the throughput gains of the CR-MLB and HO-MLB. We change the data size of traffic so that the total offered traffic load in Cell#0 is 17.6, 22, and 26.4 Mbps in Figures 6(a)-(c), respectively. The resource block (RB) usage of Cell#0 without MLB is nearly 100% when the total offered traffic load is 17.6 Mbps.

From Figure 6(a), it is found that there is little throughput gains both for the CR-MLB and HO-MLB because almost all offered traffic can be handled solely by Cell#0 even though MLB does not operate.

In Figure 6(b), we can see that high throughput gains are obtained. It is found that MLB improves the 5th percentile user throughput rather than the total throughput and about 80% gain can be achieved both with CR-MLB and HO-MLB. In HO-MLB, as $CIO_{0,1}$ increases, the throughput gains become higher although the ping-pong HO rate also becomes higher as shown in Figure 2. The throughput gains become saturated with $CIO_{0,1}$ of more than 0 dB because the overloaded offered traffic of Cell#0 is mostly transferred into neighboring cells and the RB usage of Cell#0 becomes less than 100%. In CR-MLB, as $Qoffset_{0,1}$ decreases, the throughput gains become higher without any degradation in HO performance. Compared with HO-MLB, the throughput gains of CR-MLB increase more slowly. The reason is that some UEs return to Cell#0 in the RRC connected mode due to the effect of fast fading. If the stationary UEs are dominant and the signal strengths change more slowly, it is expected that the lines of throughput gains of CR-MLB will fit closely with those of HO-MLB. In any case, CR-MLB can achieve throughput gains equivalent to HO-MLB with $Qoffset_{0,1} = 6$ dB. In addition, as an example, if we adopt a policy where the ping-pong HO rate is kept below 15%, HO-MLB cannot increase $CIO_{0,1}$ by more than –2 dB as shown in Figure 2 and the throughput gains of CR-MLB with $Qoffset_{0,1} = 6$ dB are superior to those of HO-MLB with $CIO_{0,1} = -2$.

Figure 6(c) shows the case where Cell#0 is very heavily loaded. In this case, the differences in the throughput gains between CR-MLB and HO-MLB become larger. However, if we adopt the policy that does not allow the ping-pong HO rate to rise above 15%, the throughput gains of CR-MLB with $Qoffset_{0,1} = 6$ dB are comparable to those of HO-MLB with $CIO_{0,1} = -2$.

From the above observations, we can conclude that the proposed scheme can realize load balancing effectively on a par with conventional schemes without any degradation in HO performance.

C. Performance Evaluation of CR-MLB

Next, we evaluate the proposed CR-MLB scheme over different UE distributions and traffic patterns.

Figure 7 shows the throughput gains when the ratio of the number of UEs in Cell#0 to neighboring cells is changed. The number of UEs in each cell except for Cell#0 is fixed at 20 and only the number of UEs in Cell#0 is changed. The offered data size of traffic is normalized so that the total offered traffic load in Cell#0 is 26.4 Mbps. From Figure 7, we can see that the throughput gains become higher as the ratio of UEs increases and the traffic load becomes more unbalanced.

In Figure 8, we evaluate the throughput gains by changing the total offered traffic load in Cell#0. In the evaluations, we allocate 140 UEs to Cell#0 and no UEs to neighboring cells. From Figure 8, it can be seen that the throughput gains reach the maximum when the total offered traffic load is around 22 Mbps, and then they become lower as the total offered traffic load increases. This is because when the total offered traffic load increases significantly and the RB usage of Cell#0 is much greater than 100%, the UEs' transmission traffic queues are always full and the UEs remain continuously in the RRC connected mode. In this case, there is no possibility of performing cell reselection and the performance gain of CR-MLB is reduced. This is a weak point of CR-MLB, but this situation can be avoided if CR-MLB operates before the RB usage of Cell#0 becomes greater than 100% and properly off-load the excess load of Cell#0 to the neighboring cells.

In Figure 9, the throughput gains are evaluated by changing the data size of traffic. The time interval of traffic arrival is adjusted according to the data size of traffic so that the total offered traffic load in Cell#0 is 26.4 Mbps. In the evaluations, we also allocate 140 UEs to Cell#0 and no UEs to neighboring cells. From Figure 9, we can see that more than 90% and 10% gains in the 5^{th} percentile user throughput and total throughput respectively when the data size of traffic is less than 500 KB. As the data size of traffic increases, the throughput gains becomes lower because the time that a UE stays in the RRC connected mode becomes longer due to the large data size of traffic and the possibility that the UE will return to Cell#0 in the RRC connected mode becomes higher.

Finally, from Figures 7-9, we can conclude that the proposed CR-MLB scheme is especially effective in an environment where a lot of small-size data packets are transmitted by a large number of users. Note that in the simulations of Figures 7-9, we also evaluate the throughput gains of HO-MLB and confirm that those of CR-MLB are superior or comparable to those of HO-MLB for all cases if we adopt a policy where the ping-pong HO rate is kept below 15%.

V. CONCLUSION

In this paper, we have proposed a novel MLB scheme based on CR that works in coordination with MRO. The conventional MLB schemes based on HO conflict with MRO and the simulation results show that the conventional MLB scheme cannot achieve load balancing gain without some degradation in HO performance. The proposed scheme adjusts the CR parameters but not the HO parameters, and never conflicts with MRO. Through the computer simulations, it was demonstrated that the proposed scheme can realize load balancing effectively on a par with conventional schemes without any degradation in HO performance. The simulation results have also shown that the proposed scheme is particularly effective in an environment where a lot of small-size data packets are transmitted by a large number of users, which is highly applicable to current mobile networks with explosive diffusion of smart phones. In such case, more than 10% and 90% gains can be obtained in the total throughput and 5^{th} percentile user throughput, respectively.

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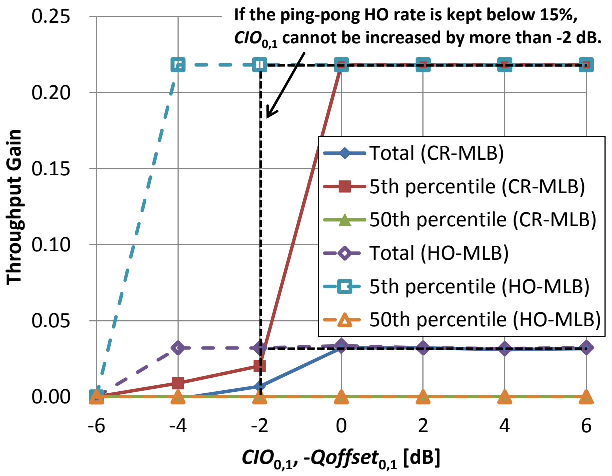
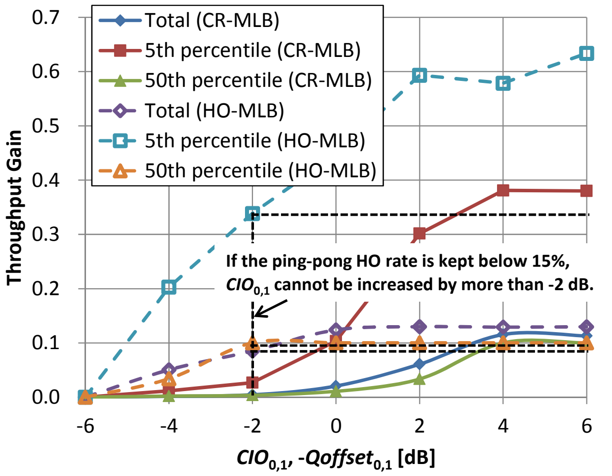
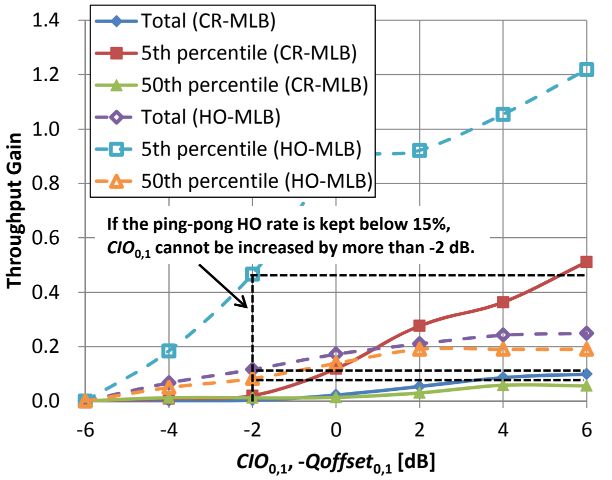


(a) Total offered traffic load in Cell#0 is 17.6 Mbps.



(b) Total offered traffic load in Cell#0 is 22 Mbps.



(c) Total offered traffic load in Cell#0 is 26.4 Mbps.

Figure 6. Throughput gains of the proposed CR-MLB and the conventional HO-MLB schemes: $Qoffset_{0,1}$ is changed from 6 to –6 dB in the CR-MLB and $CIO_{0,1}$ is changed from –6 to 6 dB in the HO-MLB.

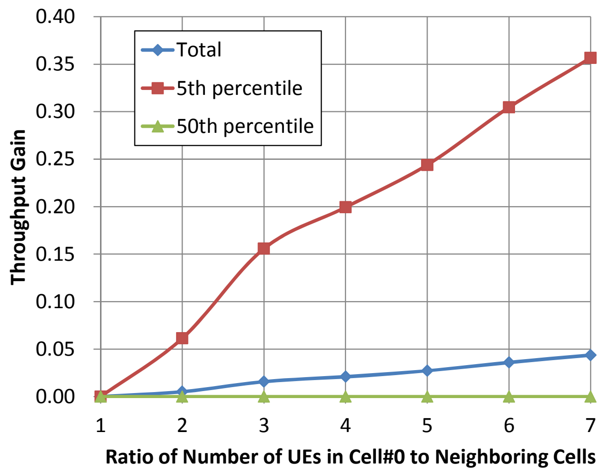


Figure 7. Throughput gains of the proposed CR-MLB scheme versus the ratio of number of UEs in Cell#0 to neighboring cells.

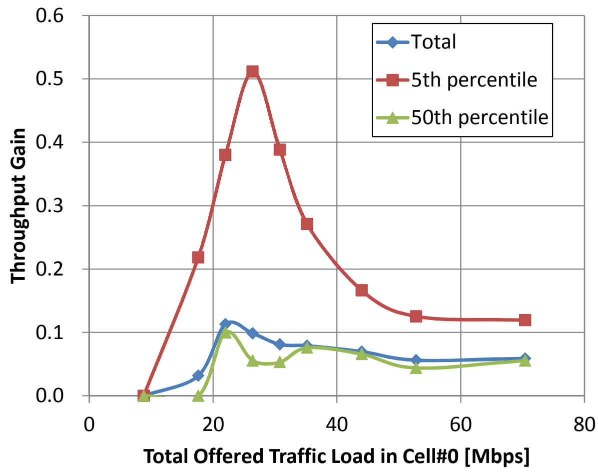


Figure 8. Throughput gains of the proposed CR-MLB scheme versus total offered traffic load in Cell#0.

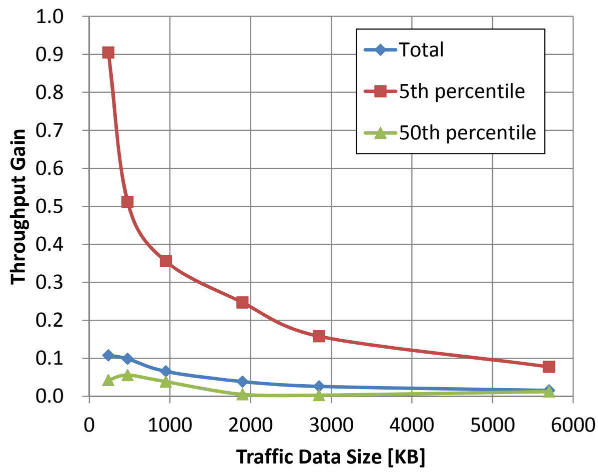


Figure 9. Throughput gains of the proposed CR-MLB scheme versus data size of traffic.

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