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Enhanced performance of long-term evolution small-cell networks using improved mobility algorithms

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ABSTRACT

With an ever-increasing number of user equipment (UE) and bandwidth demands of new applications, the deployment of dense heterogeneous cellular networks has been adopted in many network scenarios. The small cells are unable to unload the traffic due to the random UEs mobility and cells deployment. This degrades the network performance such as handover success, throughput, and load distribution. To address such a problem, we propose an enhanced mobility load-balancing algorithm for small cells. The conventional mobility load balancing (MLB) algorithms study only the fixed or adaptive thresholds of the network separately to consider the load balance process, while other MLB algorithms consider the neighboring cells of the network those experience unnecessary MLB actions. The proposed load balancing algorithms study overloaded cells and neighbors using the proposed efficiency parameter, B. To identify the overloaded cells, we propose B which compares between a pre-defined threshold and the network threshold to categorize medium and overloaded cells, based on B, the algorithm is triggered. Then, to control the shifted load to a target neighbor cell, we propose the rescue factor, f. the f ensures the load of the target cell after handover is equal or less than Ɓ. The simulation results showed a lower standard deviation and higher throughput and physical resource block utilization than surveyed algorithms.

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1. INTRODUCTION

Rising the demands of mobile communication services along with an enhancing high data rate and quality of service (QoS) stimulate the researchers to explore alternative solutions. The expected demands for wireless data in 2022 are 77 exabytes each month, which represents 49 times of 2016 demands [1]-[3]. Small cells with low power and cost, and cover ten to several hundreds of meters were introduced to support those demands and increase the capacity to play the main role in the fifth generation (5G) of cellular communication, it is used to cover blind spots of the macrocells to increase the capacity of the mobile wireless network as well as the throughput which make the small cell densification is the spine of the 5G networks [4]-[6]. The design of small cells was originally to extend the coverage of macro coverage, the more deployment of small cells in a wireless network, the better throughput and capacity the network gained. Small cells deployment increases rapidly for residential and non-residential areas, the deployment could be planned or unplanned depending on the policy of operators [7]. In small cells, the mobility of user equipment (UE) increases due to the low power of small cells and as a result of that, the imbalance load of small cells has produced across the network and the network performance degrades in terms of handover (HO) success rate and capacity. The UEs may move to a small cell with a high data rate request which is higher than the cell capacity, the cell gets congested and leads to failures of HO or poor QoS [4], [8], [9].

Diverse solutions have been proposed to decrease the problem of load balancing and enhance network performance. Mobility parameters for intra-long-term evolution (LTE) are auto-adjusted depending on the present load of the network cells to improve the system capacity [10]. However, the UE QoS shall not be affected negatively by the forced load balancing. Kwan *et al*. [11] were the first to show the efficiency of basic load balancing algorithms to lower call blockage rate and enhance cell-edge throughput based on auto-adjustment of handover settings through simulation. Lobinger *et al*. [12] overloaded cells arrange UEs according to the best nearby eNB based on reference signal received power (RSRP) measurements and traffic load of neighboring cells, it classifies the surrounding eNBs in decreasing order depending on the number of feasible handovers. If the anticipated load at the neighboring eNB does not exceed the allowed level, the entire group will be handed over. The mobility load balancing (MLB) approach introduced in [13], [14] took into account non-adjacent neighborhood cells in the optimization zone. When shifting UEs from source cells, the radio connection state of neighboring cells is considered. Enhancing MLB and handover parameter optimization (HPO) algorithms affect UE handover decisions. This interaction minimizes the desirable outcomes of every function. The coordination among MLB and HPO is examined in [15], gave a solution that leverages the capabilities of the separate algorithms to improve performance. Huang *et al*. [16] introduced a multi-traffic load balance algorithm that restores the load to enhance the capacity of the network. The algorithm improves the quality of service of the UE (QoS) by adopting a new cell reselection method, two parameters handover and time to trigger (TTT) are adaptively modified to eliminate the rates of call drop and enhance the load balancing by handing over the edge-UE of serving cells to the under-load neighbor cells. The process considers two conditions: physical resource blocks (PRB) and signal strength to detect statues of overloaded cells, and a fixed threshold is used which can’t predict adopting the variation of the network.

Hasan *et al*. [17], the adaptive mobility load-balancing algorithm in LTE small cells was presented based on the status of network load and load estimation, the algorithm adjusts the parameters of HO depending on the load traffic of the overloaded serving cell and neighbor cells. Overloaded cells are detected by the adaptive threshold, which is changed according to the average load of the network situation. To prevent the HO ping pong, the movable load from overloaded cell to light loaded neighbor cell was considered with restricted conditions to control the status of the overloaded serving and light-loaded neighbor cells. Besides, the algorithm to take into account the estimated load of both overloaded serving and light-loaded neighbor cells. However, the algorithm did not consider the traffic statues of overloaded cell as well as the estimated load of the edge UE after handover. The parameters of HO are adjusted over the network by proposing a “load balancing efficiency factor” [18]. The algorithm estimates the edge UE loads after handover and the remaining available load of neighbor cells. It specifies the operation sequence. However, offloading from an overloaded cell to light loaded cell was restricted with conditions, one of these conditions was the difference load between the overloaded and light-loaded cells is less than the gap threshold (0.1) which in some cases the offloading can’t be accomplished.

This work is structured as shown in: Section 2 explains the system model along with the adaptive threshold and load balancing measurements. Section 3 provides an overview of the load balancing control factors. The proposed algorithms are presented in section 4. Then, the performance assessment is introduced and followed by the paper's conclusions in section 5.

2. SYSTEM MODEL

The main objective of this paper is to create a balanced cell and take the advantage of the unused physical resource block (PRB) of the neighbor cell for those overloaded serving cells which can be accomplished by shifting the UEs of overloaded cell to the light loaded cell and applying some measurements. We start by creating the network architecture and the mechanism to measure the load balance. The threshold of the network is considered to identify the overloaded cells. Then, we calculate the edge-UE to be shifted to the neighbor target cells.

2.1. Network architecture

For a network of an S small cells S=[1 . . ., s], interconnected via a central self-operating network (C-SON). The small cells were introduced with x2 and operated in open access media interface, where the handover of UEs between the small cells is exchanged via the x2 interface. However, the small cells are connected with C-SON with the S1 interface and the small cells parameters are updated and optimized periodically by CSON to make the network load balance using the physical resource blocks (PRBs). In this work, a network is considered, as in Hasan [19], comprised of a set of cells, S, and a set of mobile UEs, U.

The cell group is denoted as S while the UE group is denoted as U [20]. The small cells, on the other hand, are considered to be omnidirectional and mono sectored, and they operated in open access mode. The design of the investigated access network is depicted in Figure 1 [20]. Thus, UE handovers among small cells are feasible. Subsequently, UEs can travel freely across network cells. We exclude the dual connectivity capability of UEs in this research; hence, UEs can only be coupled with one cell at a time. A SON subsystem is used for network parameter estimation [21], [22]. To accomplish load balancing, the SON gathers the relevant load information from the network and optimizes the handover parameters of the cells.

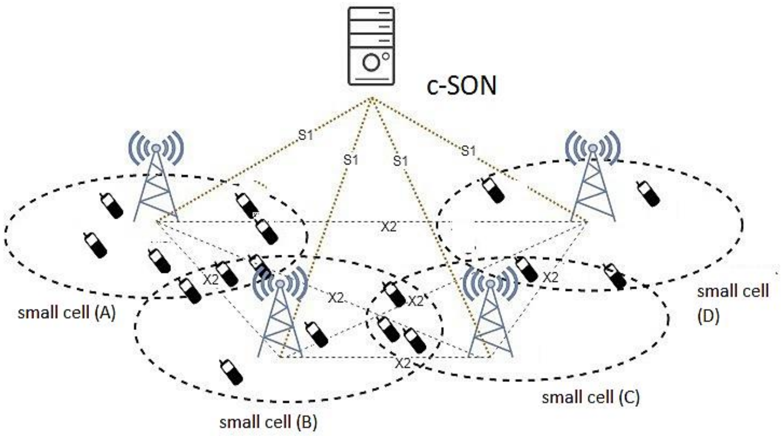

Figure 1. Access network architecture

2.2. Cell load measurements

Load balancing will enhance the performance of the wireless network by finding a measurement to calculate the cell loads (number of users, processing load, transparent load, and radio load) accurately. To do so, we must know the used PRBs of a cell to find physical resource block utilization (PRBU), which can be defined as the ratio of the used PRBs of the cell to the total PRBs in a certain time T. The average resource block utilization ratio of a small cell *i* at time t, $\bar{L}_i^t$ can be expressed as (1):

$$\bar{L}_i^t = \frac{\sum_{t\in(t-T,t)} RB_i^t}{T..S_{PRB}} \quad (1)$$

where, RB_i^t is the number of is allocated blocks and $S_{PRB}$is the total number of resource blocks at a duration time t.

For a small cell, when $\bar{L}_i^t$ is high it directs to a high load and low unused resources. However, if $\bar{L}_i^t$ reaches 1, the cell has no available resources and the moved UEs to the cell will be dropped or experienced low throughput. In this paper, we proposed an algorithm to decrease the load of the overloaded cells by shifting UEs to light-loaded neighbor cells.

2.3. Problem formulation

The main objective of this work is to take the advantage of the available PRBs of the neighbor cell for those overloaded serving cells which can be accomplished by shifting the edge UEs of the overloaded cells to the light-loaded cells by applying some measurements [23]. For a network of an S small cells at time t during the T period the average network load [7], [17], [18].

$$\bar{L}_{net}^t = \frac{\sum_{i\in S} \bar{L}_i^t}{S} \quad (2)$$

The standard deviation of $\bar{L}_{net}^t$ in the network among all cells as shown in (3):

$$\sigma(\bar{p}^t) = \frac{\sqrt{(\bar{L}_i^t - \bar{L}_{net}^t)^2}}{S} \quad (3)$$

The expression of the problem indicates minimizing the average load ratio (PBRs).

$$0 \leq RB_i^t \leq S_{PRB}, \forall i \in S, \forall t \in (t-T, t) \quad (4)$$

To move the load from an overloaded cell to a light-loaded cell and perform a balanced network, the handover parameters are adjusted adaptively and monitor the impact of the shifted load on the neighbor cell.

2.4. Load threshold calculation

MLB algorithm aims to reduce a load of overloaded cells below the predefined threshold to balance the network load. To achieve that we introduce a method to balance the network of small cell loads by categorizing the network into three levels: light load, medium load, and overload cells. The light load network is considered when the threshold is lower than the pre- threshold (P_{pre}), while when the network threshold is equal or higher than pre-threshold, the network is considered as medium loads, and the network reached the threshold, P_{Thr} which is determined as (5):

$$P_{Thr} = \frac{1}{N} \sum_{i \in N} \bar{L}_i \quad (5)$$

P_{pre} is a selected value that represents a medium-load network.

2.5. Information of serving cells edge-UEs

SON is used to achieve load balance in the network, by shifting the UEs from the overloaded serving cell to under-loaded neighbor cells. The UEs of overloaded serving cells are being nominee to be shifted to under-loaded cells, UEs trigger Athe 4 event when the neighbor cell's RSRP is better than a given threshold. Each cell of the network collects the information from its UEs to share that information with SON including the A4 event. Triggered A4 event expressed as (6).

$$Mn + Ofn + Ocn - Hys > Threshold \quad (6)$$

When A4 is accomplished, the measurements will be reported by the UEs. The small cell provides the information of edge UEs (when a reasonable threshold value is set and only UEs that report measurements are selected) and the candidate UEs are listed to be shifted from the full loaded serving cell to the light loaded neighbor cell as a result of network load balancing.

2.6. SNR estimation

The PRBs of UEs in LTE are allocated for serving cells based on channel quality indicators (CQI) that report the UEs. To achieve load balance, the required PRBs of UEs needed to be found and estimated at the neighbor cell before HO. Unfortunately, in LTE networks the information of CQI of the neighbor cells is unsupported, which forces force us to predict the required PRBs by Shannon formula. We use RSRQ measurement reports of the neighbor cell information to estimate the SINR (θ), which is defined as (7):

$$\theta = \frac{\mathrm{p}}{I+N} \quad (7)$$

where, P is serving cell signal power, I is the average interference and N is the noise. Based on [24] by using RSRP, p can be expressed as (8):

$$\mathrm{p} = x.12.\mathrm{S_{PRB}}.\mathrm{RSRP} \quad (8)$$

x Is pre antenna subcarrier factor. RSSI based on [25],

$$RSSI = P + I + N \quad (9)$$

and based on [25], RSRQ is expressed as (10):

$$RSRP = S_{\mathrm{PRB}} \cdot \frac{RSRP}{RSSI} \quad (10)$$

Therefore, from the (7)-(10), SINR becomes:

$$\theta_i = \frac{1}{\frac{1}{12.RSRQ} + x} \quad (11)$$

3. PROPOSED ALGORITHMS

In this section, we introduce our proposed algorithm regarding load balancing, which is executed in the subset of SON. Table 1 clarifies the algorithm notations. The load information is collected from all the cells to compute the threshold P_{Thr}, to that end, we propose a method to compare P_{Thr} with a predefined threshold P_{pre} to identify the higher value of them and set as a threshold which given a name of efficiency parameter $\mathcal{B}$.

$$\mathcal{B} \rightarrow max\ (P_{Thr}, P_{pre}) \quad (12)$$

$\mathcal{B}$ function is to control the algorithm triggering and categorizing the light, medium, and overloaded cells by selecting the values of P_{Thr} and P_{pre}. For instance, if the P_{Thr} is lower than P_{pre}, the network load is underloaded so, the threshold becomes P_{pre} and the algorithm is triggered for the medium-loaded cells that reach P_{pre}. When P_{Thr} *is* higher than P_{pre} then the network cells are considered as overloaded. The load balancing is occured for medium and overloaded cells until the network becomes more balanced.

Table 1. Algorithm summary notation

Notations	Description
$\bar{l_i}$	average PRBU of a small cell i at time t
P_{Thr}	Threshold load of network
Ppre	The selected value represents network medium load
Ɓ	Efficiency parameter
$\bar{L}_{(i,u)}$	Movable load of an edge cell i
$\widetilde{L_i}$	Estimated cell load after the handover of the UE u,
$\tilde{L}_{(i,u)}$	serving cell i Consumed load by UE u
$\tilde{L}_{(j,u)}$	UE u load estimated at target cell j
CIO(i→j)	Specific offset parameter of cell i for neighbor cell j

3.1. Load balancing

Shifting loads of medium/overloaded serving cells to light/medium neighbor cells is done using the proposed algorithms by adjusting the cell individual offset (CIO) parameters to detect the medium/overloaded cells of the cluster. In that end, any edge UE of overloaded cells reports RSRPs of neighbor cells is put in descending order, the edge UEs of the overloaded cells are transferred one after another so that the traffic of serving cell becomes lower than or equal to $\mathcal{B}$. However, the movable loads are estimated for serving and neighbor cells before the handover decision. In the serving cell, PRBs are used to calculate the accumulative load of the edge UEs. The movable load of an edge UE u in a serving cell i, $\bar{L}_{(i,u)}$ determined as (13):

$$\bar{L}_{(i,u)} = \frac{\sum_{t\in(t-T,t)} RB^{t}_{(i,u)}}{T.SPRB} \quad (13)$$

where, $RB^{t}_{(i,u)}$ is PRBs that are allocated by over-loaded cell i to UE u. The estimated cell load of a serving cell after handover of the UE u, $\widetilde{L_i}$ as shown in (14).

$$\widetilde{L_i} = \bar{L_i} - \bar{L}_{(i,u)} \quad (14)$$

The neighbor cell signal quality would be different for the shifted UE, therefore, the needed PRB will be different as well. The estimation load of the moved (shifted) load to a target (neighbor) cell j as shown in (15):

$$\widetilde{L_j} = \bar{L_j} + \tilde{L}_{(j,u)} \quad (15)$$

where,

$$\tilde{L}_{(j,u)} = \frac{RB_{(j,u)}}{1000.N_{PRB}} \quad (16)$$

If $\widetilde{L_j}$ is lower than $\mathcal{B}$, the values of serving and target CIO are updated by the algorithm so the candidate edge UE could be moved to the target neighbor cell as:

$$CIO(i \rightarrow j) = Mp - Mn + Hyst + \Delta \quad (17)$$

$$CIO(j \rightarrow i) = - CIO(i \rightarrow j \quad (18)$$

where, Δ is a specified LTE cemented step [21].

If $\widetilde{L_J}$ is higher than $\mathcal{B}$, we proposed a factor that transfers partition of the load that makes $\widetilde{L_J}$ lower than or equal to $\mathcal{B}$ which is named as rescue factor R_f.

$$R_{f} = \frac{\beta - \widetilde{L_J}}{L_{(i,u)}} \quad (19)$$

$$\widetilde{L_{J0}} = \overline{L_J} + R_f \widetilde{L}_{(j,u)} \quad (20)$$

Algorithms 1 and 2 represent the load balancing and unload procedure respectively, and can be summarized as:

Algorithm 1. Balancing process

calculate $\overline{L_i}$, for all small cells S
Sort S in descending order of $\overline{L_i}$
for $\forall i \in S$
  while $\overline{L_i} \geq \mathcal{B}$ do
    UNLOAD (i, $\overline{L_i}$, $\mathcal{B}$)
  end while
end for

Algorithm 2. Procedure of unload

UNLOAD (i, $\overline{L_i}$, $\mathcal{B}$)
Get target cell, τ_i of cell i
$\mathcal{B} \rightarrow max(P_{Thr}, P_{pre})$
Threshold ← $\mathcal{B}$
Sort τ_i based on RSRP by candidate UEs
for all j $\in \tau_i$ do
  if $\overline{L_i} \geq \mathcal{B}$ then
    Estimate $\overline{L_{i,u}}$ as (13) and $\widetilde{L_{j,u}}$ as in (16) and $\widetilde{L_{J0,}}$ as in (20)
    if $\widetilde{L_J} \leq \mathcal{B}$
      Set CIO$_{(i\rightarrow j)}$ as (17) and CIO$_{(j\rightarrow i)}$ as (189)
      Update $\overline{L_{i,u}} = \widetilde{L_i}$ and $L_{j,u} = \widetilde{L_J}$
    Else
      $\widetilde{L_J} \leftarrow \widetilde{L_{J0}}$
      UNLOAD (i, $\overline{L_i}$, $\mathcal{B}$)
      if UNLOAD succeed then
      Set CIO$_{(i\rightarrow j)}$ as (17) and CIO$_{(j\rightarrow i)}$ as (18)
      Update $L_{i,u} = \widetilde{L_i}$ and $L_{j,u} = \widetilde{L_{J0}}$
      end if
    end if
  end if
end for

4. RESULTS AND DISCUSSION

4.1. Environment of simulation

To investigate the proposed algorithm, we introduce the network of ten small cells and 100 UEs as in Figure 2, the network has been performed with small cells of a bandwidth of 20 MHz which enables 100 PRBs. The network transmission power was modeled to 24dBm and propagation loss as non-line of sight. Channel and QoS aware (CQA) scheduler was used to allocate resources to UEs. The pre-threshold was set to 0.35 the remaining parameters are illustrated in Table 2. 50% of the UEs were deployed as static and non-uniform, were spread over the network, and 50% in a random circular mechanism (RCM).

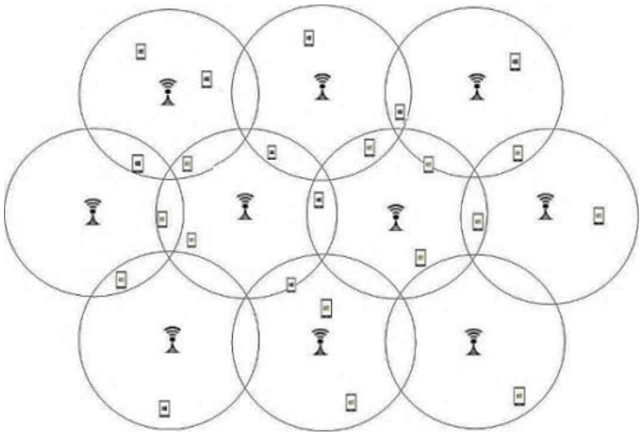

Figure 2. Simulation environment

Table 2. Simulation parameters

Parameters	Values
Cells number	20
Tx power	24dBm
Antenna mode	Isotropic
No. of users	100
System bandwidth	20MHz
Path loss	PL= 147.4+43.3 $\log_{10}$ (D)
Fading	Standard deviation 4dB, lognormal
Noise	5 dB
Resource scheduling	CQA scheduler
Hysteresis	2dB
CIO_{min} and CIO_{max}	-6 and 6 dB
TTT	256 ms
Δ	1 dB
Traffic model	1Mbps GBR
Pre-threshold	0.35

4.2. Evaluation of the network performance

The performance of two (adaptive and enhanced) MLB algorithms and the No-MLB algorithm have been reported by previous workers. These three approaches were compared to our proposed algorithm in terms of network average throughput, PRB utilization, and standard deviation to identify load distribution through the network. For each UE, the data traffic was set to 1Mbps as a guaranteed bit rate (GBR).

Figure 3, illustrates the standard deviation of the load for the previous MLB algorithms, No-MLB, and our proposed work. When the NO-MLB algorithm is used, the SD stays almost steady. However, when the MLB algorithms are used, downturns of SD values are observed.

Overall, both (adaptive and enhanced) MLBs have a steady decline in the first three minutes of the simulation due to their conditions which enable load balance triggering only if the threshold is maximum than the initial threshold which is a constant value (0.75); this level of unloading is the second level in our proposed algorithms. The proposed algorithm considers the network level of the traffic (medium or overloaded) by comparing the cell traffic with *B*, if *B* represents P_{Pre} *(0.35)*, the cell is medium loaded and the algorithm is triggered, otherwise, the cell is overloaded and the algorithm still triggered and the network becomes more balanced which affects the throughput and PRBU positively. Thus, the SD has slumped since the first minute then goes slightly when the network is more balanced. On the other hand, the SD of the surveyed algorithms turns almost steady after the fourth minute.

It showed that the proposed algorithm results in a lower standard deviation than other approaches. The average standard deviation of the proposed algorithm, enhanced and adaptive MLB algorithms, and No-MLB algorithm are 0.0358, 0.04279, 0.0458, and 0.0966, respectively. Accordingly, small cell load variation became lower which makes the network much more balanced. The network PRBs utilization varies based on the load balance. Figure 4, shows those variations for the proposed algorithm and the other approaches. However, the algorithms of MLB improved PRB utilization. On one hand, the overloaded cells are unable to assign the UEs required PRBs when No-MLB is used, while unloaded cells have many available PRBS. On the other hand, MLB algorithms distribute most of the UEs on the edges of overloaded small cells to the neighboring underloaded small cells. The proposed algorithm introduced a higher and better PRB utilization ratio than No-MLB by 12.99%, enhanced by 1.823%, and adaptive MLB algorithms by 3.96%.

Finally, the performance of throughput was evaluated. Figure 5 illustrates the average throughput with three MLB methods, the average throughput was improved using our proposed algorithm by 6.47%, 1.856% and 2% compared to the No-MLB enhanced and adaptive algorithms, respectively. The overloaded small cells affect the data rate of UEs due to the lack of PRBs to accomplish the required data rates. Therefore, in the No-MLB network, UEs of overloaded small cells experience restricted throughput. However, networks with MLB algorithms experience balanced load distribution and the small cells assign the UEs all required resources to increase the throughput of the network.

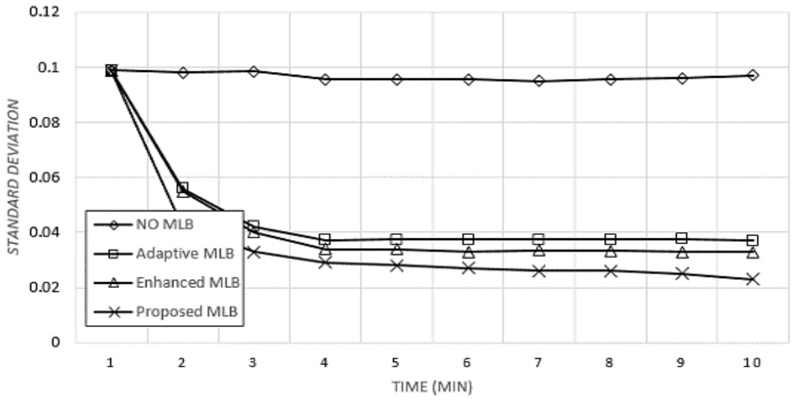

Figure 3. Load standard deviation

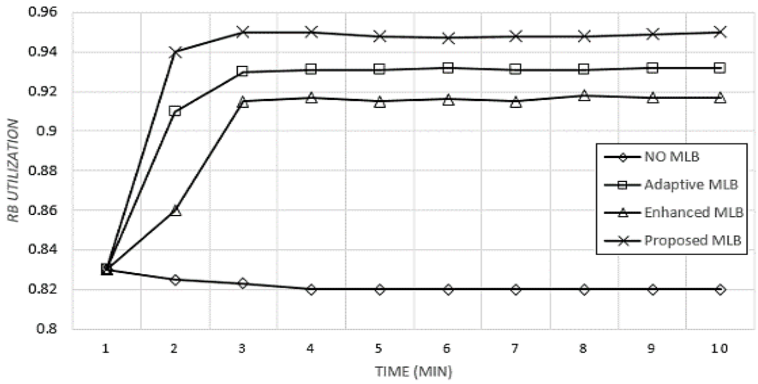

Figure 4. Resource block utilization

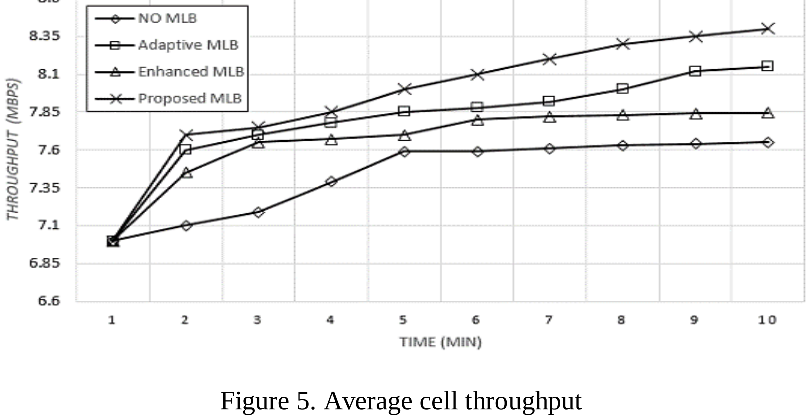

Figure 5. Average cell throughput

5. CONCLUSION

In this work, we presented an MLB algorithm that first categorizes the load status of a small cell as under-loaded, light-loaded (medium), or overloaded using the proposed efficiency parameter which considers the higher value between the pre-threshold and adaptive threshold. In the case of shifting traffic from overloaded/light-loaded cells to light-loaded/Under-loaded cells, the proposed Rescue factor compares between different load levels of the serving cell and after hand over the neighbor cell to assure target cell load is less than the adaptive threshold. The simulation results showed a lower standard deviation (SD) and higher throughput, and physical resource block utilization (PRBU) by 4.36%, 4.477%, and 7.467%, respectively with respect to No-MLB.

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