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# Throughput-Based Traffic Steering in LTE-Advanced HetNet Deployments

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***Abstract*—The objective of this paper is to propose traffic steering solutions that aim at optimizing the end-user throughput. Two different implementations of an active mode throughput-based traffic steering algorithm for Heterogeneous Networks (HetNet) are introduced. One that always forces handover of the active users towards the cell offering the highest throughput, and a second scheme that aims at maximizing the systems sum throughput. Results show that the first option brings the best performance at the cost of more than three handovers per user per second for high-load cases. The second option offers slightly lower traffic steering gains at a considerably lower cost in terms of number of handovers. The gain in terms of increased average session throughput for the second option equals 32 % at low-load, 18 % at medium-load, and 7 % at high-load conditions. The gain in the fifth percentile user session throughput is generally higher, reaching values of 36 % and 18 % for the medium- and high-load conditions.**

## I. Introduction

The extensive deployment of Heterogeneous Networks (HetNets) calls for reliable user association strategies [1], as well as optimized traffic steering and load balancing solutions. Radio handovers based on Reference Signal Received Quality (RSRQ) already constitute a passive traffic steering solution in inter-frequency scenarios due to the sensitivity of the metric to load fluctuations [2]. However, this feature not always results in an efficient approach making it necessary to develop specific algorithms. Current traffic steering solutions modify the user distribution between layers by adjusting handover boundaries or forcing handovers and cell re-selections according to a certain Key Performance Indicator (KPI). A survey of inter-frequency and inter-Radio Access Technology (RAT) traffic steering techniques for idle and connected mode, as well as a fuzzy-logic algorithm for self-tuning handovers parametrization is presented in [3]. Cell load or Physical Resource Block (PRB) utilization are common KPIs utilized in several studies. For instance, [4] defines a version of a Mobility Load Balancing (MLB) scheme where a centralized server decides the optimal values of handover margins. [5] examines an admission control algorithm for performing cell load balancing in HetNets. On the other hand, [6] proposes traffic steering procedures based on the load-based metric Composite Available Capacity (CAC) [7]. Nevertheless, the process of reacting to a change in a certain KPI by adjusting handover parameters leads to slow algorithms based on time scales of several minutes or hours. An exhaustive overview of current load balancing and user association techniques is presented in [8]. It is predicted that future 5G networks will evolve towards ever more heterogeneous systems [9], favoring the exploration of new user association solutions.

Therefore, this article proposes fast traffic steering schemes in connected mode for Long-Term Evolution (LTE) Heterogeneous Networks (HetNet) scenarios which track the dynamics of the network by explicitly monitoring the instantaneous user throughput. For each user, the throughput that could be achieved on each of the neighboring cells is estimated. Afterwards, it is selected a set of candidate cells where the highest throughput is achieved. Furthermore, traffic steering decisions may be evaluated by predicting whether forcing the handover of the users may be beneficial or not. Perfomance is evaluated by means of system level simulations.

The paper is organized as follows: Section II presents the scenario. Section III describes the proposed throughput-based traffic steering algorithms. Section IV explains the simulation setup while Section V details the obtained results. Finally, Section VI summarizes the concluding remarks.

## II. System Model and Performance Indicators

### A. Scenario Modeling

The studies are conducted under a LTE HetNet scenario characterized by a set of small cells distributed under the coverage of a macro layer. Macro and small cells layers are deployed on dedicated carrier frequencies. Both, free moving users and hot-spot users, are dropped randomly and move following random linear trajectories. Hot-spot model replicates areas with high traffic density by confining the users within a circular area around each small cell. More details on the user modeling can be found in [10]. Data traffic is generated following a Poisson arrival process with a packet call size modeled by a negative exponential distribution. To generate different load conditions in the system, the average inter arrival time is swept while the number of users remains constant. Radio Resource Control (RRC) idle mode is not considered and users are associated to only one cell at a time. A baseline case is defined with mobility parameters according to [10]. Thus, intra-frequency handovers are triggered by the A3 event and based on the Reference Signal Received Power (RSRP) metric. Inter-frequency handovers are also triggered by the A3 event but based on RSRQ. Inter-frequency measurements are triggered by the A2 event based on RSRQ.

### B. Objectives and Performance Indicators

This paper is focused on proposing dynamic traffic steering solutions which try to improve the user throughput by modifying the user-cell association. Optimized performance with a minimum number of necessary traffic steering handovers is desirable due to their impact in signaling. Low rate of Radio Link Failures (RLF) is also preferred. The set of KPIs utilized in the evaluation is constituted by: five percentile and average session throughputs, number of traffic steering handovers and RLFs rate.

## III. Throughput-Based Traffic Steering Algorithm

In order to develop a User Equipment (UE) throughput-based traffic steering algorithm it is necessary to estimate the throughput that each user could get on each of the cells of the system. In this section the mathematical framework of the throughput estimation and the methodology for extracting the target cells are presented. Afterwards, a simplified analysis of the gain that throughput-based traffic steering could achieve is detailed. The section concludes with a description of the algorithm implementation.

### A. Signal-to-Interference and Noise Ratio Estimation

The Signal-to-Interference and Noise Ratio (SINR) for a user $u$ connected to a certain serving cell $c_s \in C$, $\Gamma_{n,c_s}$, can be written as [11]:

$$\Gamma_{u,c_s} = \frac{P_{RX_{u,c_s}}}{\sum_{k=1\, k\neq c_f}^{C} \rho_k P_{RX_{u,k}} + N} \tag{1}$$

Where $C$ is the number of cells in the network, $P_{RX_{u,c_s}}$ is the wide-band received power — assuming full transmitted power — by the user $u$ from the serving cell $c_s$, $N$ is the noise power and $\rho_k \in [0,1]$ models the resource utilization of each interfering cell. In this model, $\rho_k$ scales the interference depending on the traffic conditions: as soon as there is one or more active users in a cell, all available Physical Resource Blocks (PRBs) are assumed to be scheduled and full interference is considered with $\rho_k = 1$. On the contrary, an empty cell generates no interference with $\rho_k = 0$. By utilizing the physical layer measurements performed at the UE, this formula can be also used to estimate the SINR of all cells discovered by each user even if it is not the current serving cell.

### B. Throughput Estimation

The mapping of the estimated achievable throughput of a user $u$ in a cell $c$ ($\widehat{r}_{u,c}$) in terms of the estimated SINR ($\widehat{\Gamma}_{u,c}$) can be done by means of an adjusted Shannon formula for the capacity. Assuming equal sharing of resources between all users, the equation can be written as follows:

$$\widehat{r}_{u,c} = W_c \log_2\left(1 + \widehat{\Gamma}_{u,c}\right) \cdot \frac{1}{N_c + 1} \qquad [bps] \tag{2}$$

Where $W_c$ is the cell bandwidth and $N_c$ is the number of active users in the cell. The term $N_c + 1$ predicts how the long-term averaged UE throughput varies when adding a new user to the current number of active users in the cell. In a system with a total number of $N$ active users, the estimation of the throughput for all UEs and all cells can be grouped in a matrix, $\mathbf{R}$, of dimensions $N \times C$:

$$\mathbf{R} = \begin{bmatrix} \widehat{r}_{1,1} & r_{1,2} & \widehat{r}_{1,3} & \dots & \widehat{r}_{1,C} \\ \widehat{r}_{2,1} & 0 & r_{2,3} & \dots & \widehat{r}_{2,C} \\ \widehat{r}_{3,1} & \widehat{r}_{3,2} & r_{3,3} & \dots & \widehat{r}_{3,C} \\ \dots & \dots & \dots & \dots & \dots \\ r_{N,1} & \widehat{r}_{N,2} & 0 & \dots & \widehat{r}_{N,C} \end{bmatrix} \tag{3}$$

Where non hatted elements refer to the experienced throughput in the current serving cell. If the UE is not able to measure a certain cell, the correspondent element is marked with a zero.

### C. Target Cells Selection

Once the matrix $\mathbf{R}$ has been created, the candidate target cells can be extracted. In order to reduce the algorithm's complexity and possible delays when selecting the final target cell for each user in practical networks, the set of candidates is limited. Hence, for each active user all cells are ranked and the 2 best cells in terms of estimated throughput are identified: the cell where the user $u$ achieves the maximum estimated throughput, $t_{u,1}$, and the cell where the user $u$ achieves the second maximum throughput, $t_{u,2}$. This can be expressed as:

$$\begin{aligned} t_{u,1} &= \arg\max_j \{\widehat{r}_{u,j}\} \\ t_{u,2} &= \arg\max_{k\neq j} \{\widehat{r}_{u,k}\} \end{aligned} \tag{4}$$

All candidate cells for all active users can be grouped in a new matrix $\mathbf{T}$ of size $N \times 2$, expressed as:

$$\mathbf{T} = \begin{bmatrix} t_{1,1} & t_{1,2} \\ t_{2,1} & t_{2,2} \\ t_{3,1} & t_{3,2} \\ \dots & \dots \\ t_{N,1} & t_{N,2} \end{bmatrix} \tag{5}$$

In case a UE is not able to measure any other cell but the current server, the second target cell is marked with 0.

### D. Theoretical Analysis of the Gain

A simplified single-user traffic steering decision is analyzed to investigate the potential gain that can be obtained when a user is served by cell $A$ and it is steered towards cell $B$. Both, serving and target cells, operate with the same bandwidth. Full interference ($\rho_k = 1$) is assumed. According to (1), the SINR in the serving cell and the estimated SINR in the target can be calculated as:

$$\Gamma_{u,A} = \frac{P_{RX_{u,A}}}{\sum_{k=1\, k\neq A}^{C} P_{RX_{u,k}} + N} \tag{6}$$

$$\widehat{\Gamma}_{u,B} = \frac{P_{RX_{u,B}}}{\sum_{k=1\, k\neq B}^{C} P_{RX_{u,k}} + N} \tag{7}$$

Let $N_A$ and $N_B$ be the number of active users in cell $A$ and $B$ respectively before the traffic steering action. Following (2), the throughput in both, serving and target cell follows:

$$r_{u,A} = W_c \cdot log_2\left(1 + \Gamma_{u,A}\right) \cdot \frac{1}{N_A} \tag{8}$$

$$\widehat{r}_{u,B} = W_c \cdot log_2\left(1 + \widehat{\Gamma}_{u,B}\right) \cdot \frac{1}{N_B + 1} \tag{9}$$

The ratio of these two estimates the throughput gain when steering the user:

$$\frac{\widehat{r}_{u,B}}{r_{u,A}} = \frac{N_A}{N_B + 1} \cdot \frac{log_2\left(1 - \frac{P_{RX_{u,B}}}{\sum_{k=1}^{C} P_k + N}\right)}{log_2\left(1 - \frac{P_{RX_{u,A}}}{\sum_{k=1}^{C} P_k + N}\right)} \tag{10}$$

From (10) it can be seen that the achievable gain depends on the ratio between the number of active UEs in the serving

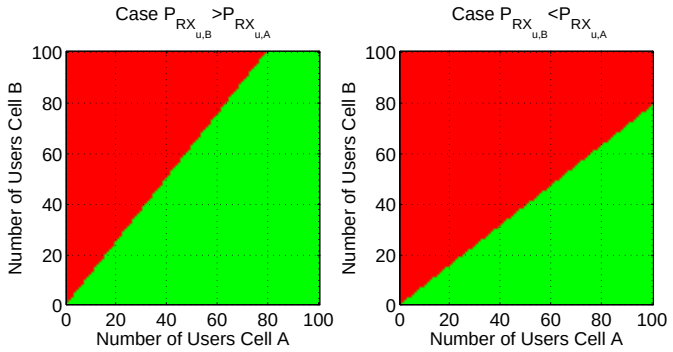


Fig. 1. Potential gain regions when moving one user from cell A to cell B as a function of the number of active users in both cells. The red and green colors refer to the regions of losses and gain respectively.

and target, and the received power by the user from both cells. Figure 1 shows the different regions of gain for the cases when the received power from the target is higher than the serving and vice-versa. The red area points out the region where the quotient $\frac{\widehat{r}_{u,B}}{\widehat{r}_{u,A}} < 1$, whereas the green color refers to the cases where $\frac{\widehat{r}_{u,B}}{\widehat{r}_{u,A}} > 1$. When the received power from serving and target cells is the same, the gain and loss regions are symmetric. In such a case, to obtain any gain the number of users in the target cell should be lower than the number of users in the serving. If the received power from the target cell is lower than the one from the current serving, the gain region shrinks. However, the opposite effect occurs when the target cell is stronger than the current serving, e.g. when handover a user from the serving macro to a pico cell on the vicinity. In this case, a gain is obtained even if there are more users in the target cell than in the serving. This simplified analysis does not take into account that a third cell $C$ may simultaneously steer users towards cell $B$ possibly reducing the gain.

### *E. Traffic Steering – Option 1*

Traffic Steering – Option 1 is an aggressive method which consists of forcing the handover of the active users towards the cell where the estimated throughput is higher — i.e. towards the first target $t_1$ — each time the algorithm is triggered. This approach does not take into account how existing users in the target cell may be influenced. If many active users select the same target cell at a given time, the obtained throughput may differ from the estimated by (2) since only one additional user is taken into account in the equation. Therefore, this one can be considered as a partially-blind option where the consequences of the traffic steering process are not explicitly taken into account.

### *F. Traffic Steering – Option 2*

In the second approach, the users are steered if, and only if, it is predicted that the sum of the estimated throughput of all active users of the entire system increases after the offloading process. With this condition, the method tries to reduce unnecessary traffic steering handovers. This task can be addressed by solving an optimization problem where the sum of all instantaneous user throughputs is maximized according to the following objective function:

$$r_{max} = \max \left\{ \sum_{u=1}^{N} r_{u,c_i} \right\} \tag{11}$$

Where $c_i \in C$. $r_{u,c_i}$ is the instantaneous achievable throughput by the user $u$ when connected to cell $c_i$. $r_{max}$ constitutes the observed metric. The matrix $\mathbf{T}$ previously defined offers to each user two different candidate cells where to be steered. As a result, three possible disjoint decisions for this implementation are proposed: 1) to steer all active users to the first target, 2) to steer the users to a specific combination of first and second targets, or 3) to not steer any user at all. One, and only one of these three options is selected depending on which one maximizes Equation 11. In order to select the best option, it is necessary to predict what is the impact of each decision by an iterative process where different versions of the matrix $\mathbf{R}$ and the metric $r_{max}$ are calculated taking into account the user association of each possible case. In total, three iterations are needed. A full step by step description of this implementation can be seen in Algorithm 1.

**Algorithm 1** Traffic Steering – Option 2

Calculate initial metric $r_{max_0}$
For each active user estimate $\widehat{\Gamma}_{u,c}$ and $\widehat{r}_{u,c}$
Create initial $\mathbf{R_0}$ matrix
Extract target cells matrix $\mathbf{T}$
Calculate $\mathbf{R_1}$ having each user connected to its first target cell, $t_1$
Update metric $r_{max_1} = \max \left\{ \sum_{n=1}^{N} \widehat{r}_{n,t_1} \right\}$
**if** $r_{max_1} > r_{max_0}$ **then**
  Handover each user to its $t_1$
**else**
  $M_1 =$ Users which get better throughput in $t_1$
  $M_2 =$ Users which do not get better throughput in $t_1$
  Calculate $\mathbf{R_2}$ with $M_1$ users in its $t_1$ **and** $M_2$ users in its $t_2$
  Update metric $r_{max_2} = \max \left\{ \sum_{i=1}^{M_1} \widehat{r}_{i,t_1} + \sum_{j=1}^{M_2} \widehat{r}_{j,t_2} \right\}$
  **if** $(r_{max_2} > r_{max_1})$ **and** $(r_{max_2} > r_{max_0})$ **then**
    Connect $M_1$ users to first target
    Connect $M_2$ users to second target
  **end if**
**end if**

The initial state is given by the calculation of the observed metric with all the active users connected to their current serving cell and the creation of the matrix which contains the estimation of the achievable user throughput in the neighboring cells. From this matrix, the sets of candidate target cells per user are extracted. Subsequently, an evaluation phase starts and, considering all users connected to their first target cell, an updated version of the estimated user throughput matrix and the observed metric are calculated. If the updated version of the metric results in bigger value than the initial one, the algorithm finishes by steering all active users to their first candidate cell. Otherwise, the algorithm selects which users perceive a loss in their throughput when connected to the first target cell. Let's assume that over $N$ active users $M_1$ get better throughput and $M_2$ users do not get any improvement being connected to the first candidate. The algorithm creates a new estimated user throughput matrix with the $M_1$ users steered to their first target, and the $M_2$ users to their second one. With this information, a new value of the metric is calculated. If, in this case, the metric is bigger than the last two, this user association is selected. Otherwise, since connecting all users to the first target or to a specific combination of first and second target does not bring any benefit, the algorithm cancels any attempt of steering them.

## IV. Performance Evaluation

The performance of the proposed traffic steering algorithms are evaluated by means of extensive dynamic system level simulations in the HetNet scenario $2a$ defined by the 3rd

Generation Partnership Project (3GPP) in [12]. The hexagonal network is characterized by 21 macro cells and 42 small cells randomly deployed, following a ratio of 2 small cells per macro area. The initial conditions of the simulation are defined by $1/3$ of the users dropped on each macro coverage area while the remaining $2/3$ are confined within circular areas of 50 m radius around each small cell. In total, 30 users per macro area are deployed. All users are initially connected to the cell with highest RSRP regardless of the cell type. For each simulation time-step the down-link SINR is calculated taking into account the propagation characteristics of all links. The SINR-throughput mapping is according to an abstract layer which includes the effect of scheduling and link adaptation. At the end of each step the KPIs are collected. Users are moving in different set of simulations at 3 km/h or 50 km/h.

TABLE I. SIMULATION PARAMETERS

| **Parameter** | **Value** |
|---|---|
| Scenario | 3GPP HetNet Scenario 2a [12] |
| Number of macro cells | 21 |
| Number of pico cells | 42 (2 small cells per macro area) |
| Macro Inter-Site Distance (ISD) | 500 m |
| Frequencies | Macro: 1800 MHz. Pico: 2600 MHz |
| Bandwidth | Macro: 10 MHz. Pico: 10 MHz |
| Transmitted Power | Macro: 46 dBm. Pico: 30 dBm |
| Number of UEs | 630 (30 per macro area) |
| Users speed | 3 km/h or 50 km/h |
| Packet call size | Negative exponential distributed with 10 Mbits mean |
| Intra-Frequency Mobility | Baseline: A3 RSRP-based. 2dB offset. 160 ms TTT<br>TS ON: A2 RSRQ-based. -16 dB thr. 480 ms TTT |
| Inter-Frequency Mobility | Baseline: A3 RSRQ-based. 4dB offset. 160 ms TTT<br>TS ON: A2 RSRQ-based. -16 dB thr. 480 ms TTT |
| Inter-Frequency Meas | A2 RSRQ-based. -10 dB threshold |
| Simulation Time | 1000 s (3 km/h) or 50 s (50 km/h) |
| Simulation Time Step | 50 ms |
| Triggering Period | TS - Option 1: 50ms. TS - Option 2: When necessary |

The offered load per macro area varies from 18 Mbps (low-load) to 34 Mbps (high-load). The whole simulation time is 1000 s or 50 s for user speeds of 3 km/h or 50 km/h respectively. Three simulation cases are investigated. First, a baseline scenario is defined in order to explore the performance when inter-frequency handovers triggered by the A3 event and based on RSRQ balance the load between both layers. In this case, handover parametrization follows recommendations from [10]. Traffic Steering – Option 1 and 2 define the other two simulation cases. Whenever any traffic steering implementation is enabled, mobility parameters are set to a more relaxed configuration to avoid the radio handovers redoing traffic steering decisions. This configuration also targets to minimize RLFs for users in bad conditions. The performance is evaluated by comparing the three cases. A complete definition of the simulation parameters is shown in Table I. The utilized system level simulator has been used in various 3GPP studies. As a reference, additional HetNet mobility performance results produced by the simulator can be found in [13].

## V. SIMULATION RESULTS

Figure 2 shows the average session throughput of all users moving at 3 and 50 km/h in different offered traffic conditions per macro area. Although the algorithms base their decisions on the instantaneous user throughput, the impact to the end-user is analyzed by examining the session throughput. The best performance is given by Traffic Steering – Option 1, closely followed by Option 2. As the different simulated speed cases are under the same handover parameterization, the performance of the baseline case drops when increasing the user speed. Despite the speed difference, traffic steering brings gains in both cases. The observed fluctuations at 50 km/h are due to the limited number of collected samples as the simulation is set to 50 s. Nevertheless, a clear tendency can be extracted from the chart.

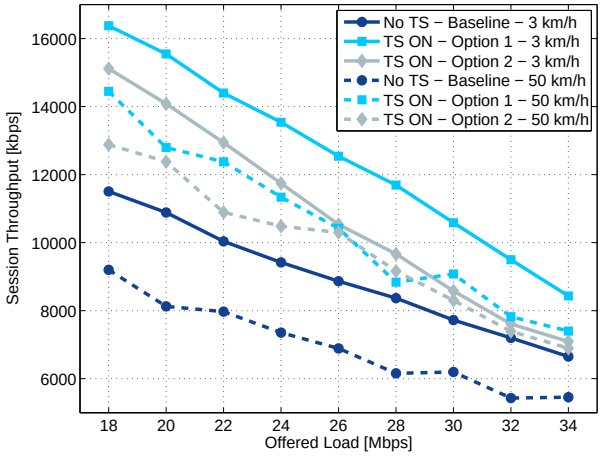


Fig. 2. Averaged UE session throughput for each simulated offered load case with users moving at 3 and 50 km/h.

Figure 3 depicts the session throughput gains for both traffic steering implementations, compared to the baseline case, and the number of traffic steering handovers for both methods. As Traffic Steering – Option 1 tracks the fast traffic fluctuations of the network by always trying to obtain the best user throughput, this implementation achieves the best gains. However, this performance comes with the high price of performing a large number of handovers. On the other hand, by applying the condition of moving users, if and only if, there is an augmentation in the sum of the user throughput, Traffic Steering – Option 2 reduces considerably the number of necessary handovers. Although this improvement in signaling has a cost in terms of achievable gain, the results do not show big losses in performance. For instance, when users are moving at 3 km/h in a system with 26 Mbps of offered load, a reduction of 41 % in the number of traffic steering handovers implies only a reduction of 22 % point in the session throughput gain. As a reference, the maximum number of handovers in the baseline case is observed at low-load with an absolute value of 0.37 handovers per user per second. Regarding the gain of the fifth-percentile session throughput at 3 km/h, the values obtained for Option 1 and 2 are: 107 % and 69 % for low-load, 98 % and 36 % for medium-load (26 Mbps), and 90 % and 18 % for high-load conditions.

The average macro and pico PRB utilization for 3 km/h case is depicted in Figure 4. As it can be noticed, for the baseline case, the PRB utilization tends to be equalized in both layers as the load increases. This is due to the fact that the RSRQ radio handovers already steer some users towards the pico layer. However, for high-load cases, the macro layer is close to overload. Traffic steering decreases considerably the overall load of the system bringing gains in the user

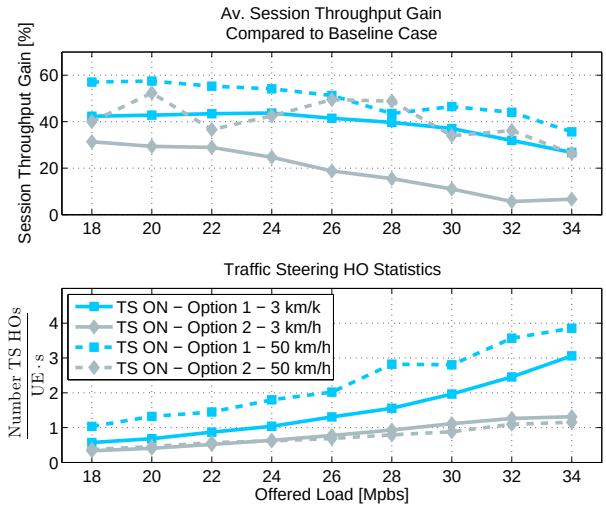


Fig. 3. UE session throughput gains and number of traffic steering handovers for each simulated offered load case with users moving at 3 and 50 km/h.

throughput and hence, reducing the duration of each session. Traffic Steering – Option 1 brings the biggest gain due to the elevated number of handovers however, the contribution of Option 2 with less signaling rate, is worthy to highlight. Some RLFs are observed when users are moving at 50 km/h in the baseline case nevertheless, they are eliminated whenever any of the traffic steering implementations are switched-on.

### A. Throughput Estimation Error

As both of the considered traffic steering algorithms are based on throughput estimations, the accuracy of these have been assessed as well. For the sake of simplicity, we here present the throughput estimation accuracy for Traffic Steering – Option 2, where the sum throughput is estimated. Let us denote the estimated sum throughput as $\hat{r}_{sum}$ and the real experienced sum throughput after performing the traffic steering decisions as $r_{sum}$. Given those, the relative estimation error is expressed as $\epsilon = \frac{\hat{r}_{sum} - r_{sum}}{r_{sum}}$. During the simulations, statistics for $\epsilon$ reveals that the sum throughput estimate is unbiased as the sample mean of $\epsilon$ is practically zero. Furthermore, the standard deviation of the relative estimation error is found to be rather modest, taking values of 2.1 % and 2.9 % for 3 km/h and 50 km/h respectively.

## VI. Conclusions

In this paper two different methods of a throughput-based traffic steering algorithm are proposed. One that forces the handover of the active users on each time step towards the cell where the highest achievable throughput is predicted, and a second method which forces the handover if, and only if, an augmentation in the sum of the overall user throughput is estimated. Exhaustive system level simulations of a dual-layer HetNet scenario are conducted to evaluate their performance. Results show that the first scheme achieves better performance in terms of the average user session throughput and overall PRB utilization at the cost of a large numbers of handovers. More promising is the second implementation as it reduces the number of handovers by 41 %, while still offering session throughput gains of 19 % for medium-load at 3 km/h.

Given the attractive gains of the presented traffic steering algorithms, it is suggested to further study the details of the required inter-Evolve Node B (eNodeB) signaling, the related

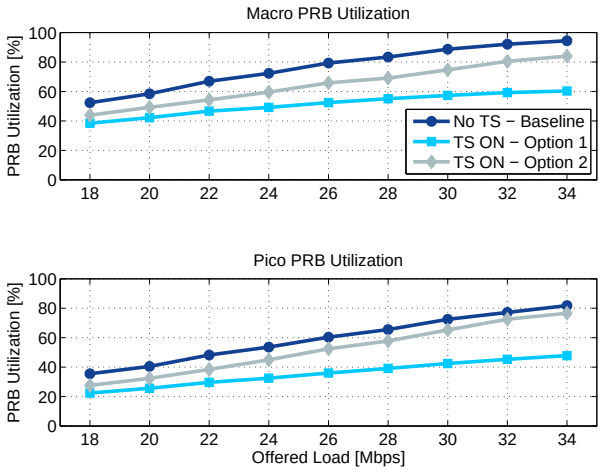


Fig. 4. Macro and Pico PRB utilization. 3 km/h simulation case.

eNodeB-to-UE signaling for the handovers, as well as the impact on the associated data interruption times. It is also recommended to analyze the time complexity of the algorithms and its applicability in practical cellular networks with different user traffic requirements.

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