Performance Enhancement of Heterogeneous Networks via Dense Clusterization and Higher Order Modulation

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***Abstract*—Heterogeneous Networks are introduced in LTE-Advanced in order to fulfill the demanding necessity for more network capacity by the deployment of small cell nodes. In this paper, we study the dense deployment of small cells in hotspot to cover the users' data requests. The aim is to determine the optimum number of outdoor nodes per hotspot to achieve highest average user throughput. The results indicate that there is a range of optimum number of small cell nodes depending on the density of data traffic and the trade-off between available capacity and inter small cell interference. Introducing the small cells layer results in better channel conditions for some users that are close to small cells nodes. Thus, this encourages the usage of higher order modulation schemes like 256QAM. Adopting 256QAM infers that impairments caused by transmitter and receiver circuitry should be considered while evaluating the feasibility of 256QAM for outdoor small cells in heterogeneous networks. Results show that impairments have considerable negative effect on 256QAM throughput gains compared impairments-free system.**

Keywords—Heterogeneous Networks; Higher Order Modulation; Outdoor Small Cells; 256QAM; Transmitter & Receiver Impairments.

I. INTRODUCTION

Small Cells (SCs) and Heterogeneous Networks (HetNets) are considered one of the LTE-Advanced research topics that grasped interest in the recent time [1]. It is expected that the data rates requested by mobile subscribers will increase significantly in the coming years [2]. In addition to that, LTE-Advanced will need to satisfy new usage models that involve a giant hump in some services especially mobile data and video streaming. HetNets appears as a promising solution for LTE-Advanced to provide higher data rates and quality of service in the areas of high density of users.

HetNets are access networks consisting of multiple operating layers with different characteristics. The main layer is the Macro-layer that consists of Macrocell Nodes (MCNs) with high transmission power; and it is responsible for the coverage in an entire site. While the SCs layer, which is based on low-power nodes, is deployed in areas of high throughput requirements known as Hotspots.

The SCs layer nodes can be categorized based on density of deployment to sparsely dropped SCs or densely dropped SCs in hotspot areas [1]. SCs nodes also differ in range of coverage ranging from small apartments /offices (Femto Cells) supporting Closed Subscriber Group (CSG) functionality [3][4] to larger areas like halls and airports (Pico Cells). Another dimension of classification is the deployment environment; since SC nodes can be deployed indoors or outdoors at lower heights compared to MCNs.

The deployment of SCs results in interference problems for User Equipment (UEs) in both layers [4][5] that should be suppressed by different interference mitigation algorithms, such as, ICIC, eICIC and FeICIC [6][7] and power control techniques [3][4].

In this paper, we focus on boosting UE throughput by enhancing the performance of HetNets with outdoor SCs. The enhancement is achieved using two aspects. The first aspect is increasing the density of clusterization of SCs in hotspots. The second aspect is the application of higher order modulations schemes like 256QAM for higher data rates at user terminals.

Dense clusterization of SCs is used at hotspots to provide closer serving nodes, i.e., better channel conditions, to more UEs for better network capacity and reducing traffic load on Macro layer. The disadvantage of the high density deployment of SCs is the non-negligible inter-SC interference. This harms Signal to Interference and Noise Ratio (SINR) between UEs and SC nodes resulting in throttled UE throughput. Thus, maintaining an optimum density of SC deployment is required to taper interference and to maximize throughput for UEs.

Being closer to UEs, less propagation losses to be suffered and better channel conditions and SINR are maintained between UEs and SCs nodes. Thus, higher performance could be achieved by introducing higher order modulation schemes like 256QAM to be an available option on the SC layer for UEs served by SCs. We study the gain achieved by 256QAM scheme in an outdoor HetNet environment and the negative effect of transmitter and receiver impairments on these gains.

The rest of the paper is organized as follows: Section II presents simulation environment and parameters. In Section III, the effect of the SCs density on user throughput is discussed. We introduce 256QAM modulation scheme and transmitter and receiver impairments modeling in Section IV. Section V provides the results of performance evaluation of supporting higher order modulation in the existence of transmitter and receiver impairments. Finally, Section VI concludes the paper.

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II. SIMULATION PARAMETERS

The simulated network layout is based on 7 hexagonal sites where each site is divided into three sectors as shown in Figure 1. Each sector has one hotspot area of 70m radius called cluster with 67% of UEs dropped in it and the rest of UEs are uniformly dropped in sector. The cluster has (N) SC nodes dropped uniformly within a radius of 50m from cluster center [8]. To model real cases, 80% of UEs are assumed to be indoor UEs suffering outdoor to indoor losses [8].

The Macro layer and SC layer operate in non-co-channel mode (no inter-layer interference). MCNs operate at center frequency of 2GHz. While on the other side, SCs operate at center frequency of 3.5 GHz. Bandwidth of 10 MHz is available at both center frequencies. Communication is fully downlink and stochastic channel models were used for macro layer and SCs layer [9].

Data traffic is modeled using bursty FTP traffic model 1 [10] as a closer traffic model to real traffic. In this model, one or more UEs are assumed to request data download of size 0.5 MB from the serving node at random time instants of a Poisson distribution (Exponential inter-request time periods). Simulation parameters are described in Tables I, II, III.

Simulations were held on a MATLAB-based System Level Simulator (SLS). The SLS models the propagation losses and the fast fading channel for the urban macrocell (UMa) and urban microcell (UMi) environments. Then, UEs are associated with the serving nodes based on Reference Signal Received Quality (RSRQ) which is calculated by

$$RSRQ = (N_{RB} * RSRP) / (RSSI) \qquad (1)$$

where RSRP stands for Reference Signal Received Power, N_{RB} is the number of resource blocks and RSSI is the Received Signal Strength Indicator including received power from serving and interfering nodes and noise power [11].

RSRQ is used since it takes interference into consideration which is a decisive factor when HetNet layers operate at different frequencies and the interference profile differs between the macro layer and SC layer. RSRP (received power) as a basis for UE association is deceiving in the case of non-co-channel mode operation since you may get high received power from a serving node but at the same time suffer strong interference and deteriorated SINR. UE association process starts when UE request data download. It is worth noting that SC nodes that do not send data to any UEs, at association instant, are not considered when calculating interference part in RSRQ. This makes association decision depending on instantaneous interference profile derived from the instantaneous traffic in the network instead of assuming worst case one in which all nodes are assumed sending data and causing interference. Interference caused due to CRS signaling is also taken into consideration.

Then, SLS generates the channel matrices and the interference covariance matrices used in modeling received signal. The received signal by kth UE (y_k) is given by

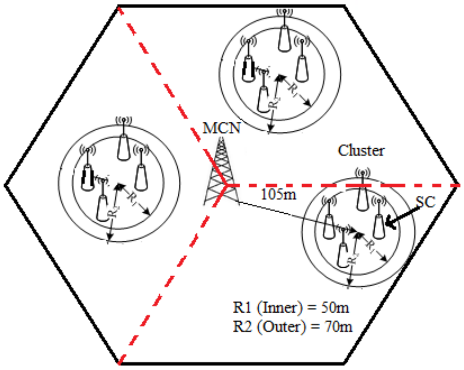

Figure 1. Network Layout for a Hexagonal Site

TABLE I. LAYOUT PARAMETERS

Parameter	Value
Deployment Grid	Hexagonal
Number of Sites / Cells	7 Sites / 21 Cells
Number of Clusters per Cell	1
Number of SCs per Cluster	N = [1:10]
Number of UEs per Cell	60
Percentage of UEs in Cluster	67%
Percentage of Indoor UEs	80%

TABLE II. SYSTEM PARAMETERS

Parameter	Value
Bandwidth (Macro/SCs)	10 MHz / 10 MHz
Carrier Frequency (Macro/SCs)	2 GHz / 3.5 GHz
Modulation	Up to 64QAM
Traffic Modeling	Non Full Buffer (λ=6,10)
File Size	0.5 MB
Scheduling	Proportional Fair with Outer-Loop Link Adaptation 0.15 dB
Receiver	Interference Aware Receiver (MMSE-IRC)
Cell Association	RSRQ

TABLE III. LINK & CHANNEL PARAMETERS

Parameter	Value
Macro Channel Model	ITU-UMa [9]
SCs Channel Model	ITU-UMi [9]
Antenna Configuration	2Tx X 2Rx , Cross Polarized
MIMO Mode	SU-MIMO with Adaptive Rank
Channel Estimation	Perfect
CRS Interference	Modeled – Alternative 2 [12]
UE Feedback	Code Book Based

$$y_k = \sqrt{\alpha_k}\; H_k W_k x_k + \sum_{i=1}^{I} \left(\sqrt{\alpha_i}\; H_i W_i x_i \right) + n \qquad (2)$$

where (H_k, H_i) represent the channel between kth UE and the serving node and any of the (I) interfering nodes, respectively. (W_k) is the precoding matrix by the serving node for the kth UE. (W_i) is the precoding matrix by the interfering nodes for other UEs. (x_k) is the transmitted signals for kth UE. On the other hand, (x_i) is the transmitted signals for other UEs by interfering nodes. (α_k) represents the received power from the serving node and (α_i) represents the received power from the ith interfering node. Finally, n is the zero mean additive white Gaussian noise of the channel.

Then modulation order is chosen based on the instantaneous SINR (γ) calculated by

$$\gamma = \frac{\propto_k \left\| \sum_{n=1}^{N_t} H_k\, W_k(:,n) \right\|^2}{\sum_{i=1}^{I} \left(\propto_i \left\| \sum_{n=1}^{N_t} H_i\, W_i(:,n) \right\|^2 \right) + \sigma_n^2} \tag{3}$$

Afterwards, throughput is calculated by summing Transport Block Sizes (TBSs) (The higher the modulation order, the bigger the TBS sent to the UE) transferred on the downlink excluding dropped blocks to consider block error rate.

III. DENSE CLUSTERIZATION OF SMALL CELLS

Hotspot areas of the macrocell are congested with high density of UEs of huge request of data. Such requests are satisfied by deploying a cluster of SCs to provide an acceptable quality of service for these UEs.

The tradeoff appears upon the decision of the density of SCs deployed per hotspot. Increasing the SCs will provide more resources for UEs. The advantages of this approach are the decrease in the waiting or blocking probability and the system will usually not suffer resources starvation or high latency. On the other hand, increasing the number of SCs in hotspot leads to high interference among SC (inter-SC interference) and a reduction in the received power at UEs.

The resources needed to keep the system functional under given traffic conditions enforce a lower bound on the number of SCs to be deployed. While, the inter-SC interference caused by dense deployment of SCs enforces an upper bound constraint on the number of SCs to be deployed in a hotspot area. In addition to that, other factors may play a role in the tradeoff like the cost and the power consumption.

In this section, our target is to define an optimum density of SCs in a hotspot between the two bounds. At this optimum point, highest UE throughput is achieved due to tolerable inter-SC interference and the existence of enough resources to fulfill UEs requests.

We held system level simulations and set the environment as described in Section II. The number of SCs per cluster is varied in the range from 1 to 10 in order to find the optimum density of SCs per cluster to serve hotspot UEs. The optimum density of SC nodes in a cluster is achieved when all UEs (MCN UEs and SC UEs) have their average throughput maximized considering different traffic loads. All UEs are considered since the ratio of association is not constant when the numbers of SCs per cluster is changed due to the change in interference profile considered in RSRQ association.

To achieve this target, average UE throughput is measured for all UEs at different number of SCs per cluster and at different non full buffer traffic loads (λ = 6, 10, 16 user requests for file download per second per geographical cell).

By applying this criterion of throughput maximization, the number of SCs for good performance depends on traffic load. For low traffic load (λ = 6), the maximum throughput occurs when hotspot has 4 SCs as shown in Table IV.

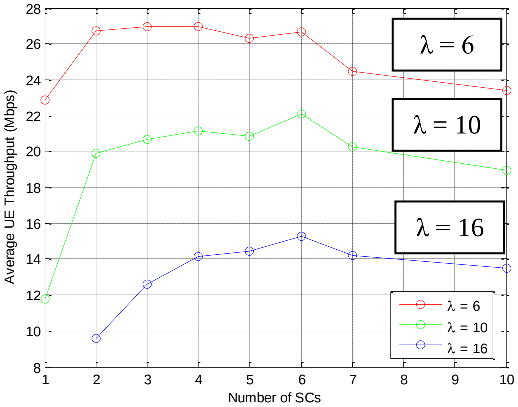

Figure 2. Mean UE Throughput for all UEs vs. Number of SCs

TABLE IV. DENSE CLUSTERIZATION OF SMALL CELLS RESULTS

N SCs	All UEs Throughput (Mbps) λ = 6	All UEs Throughput (Mbps) λ = 10	All UEs Throughput (Mbps) λ = 16
1	22.87	11.74	N/A
2	26.74	19.90	9.56
3	26.96	20.70	12.62
4	**26.98**	21.13	14.17
5	26.31	20.85	14.45
6	26.67	**22.10**	**15.26**
7	24.48	20.23	14.18
10	23.41	18.93	13.51
Mean Resource Utilization (%)	8.58%	15.6%	22.5%

The throughput provided by 2 or 3 SCs is also close to the maximum so it may be a good option of cutting cost without big loss in performance (< 1%). At medium traffic load (λ = 10), we can notice the traverse in the peak throughput to 6 SCs per hotspot. This is expected with the increase of traffic where the need of resources becomes more urgent than need for a good SINR. This conclusion is confirmed for heavy traffic (λ = 16) with 6 SCs per hotpot is the optimum choice for SC density in this case. For heavy traffic, low number of SCs provide very low throughput like the case of 2 SCs or cannot handle the UE requests like the case of 1 SC.

Looking at the extremes, with only 1SC per hotspot, system cannot handle heavy traffic and it suffers lack of resources at low and medium traffic cases. While with 10 SCs per hotspot, the inter-SC interference increases and becomes very dominant and outweighs the capacity added to the network by adding SCs.

Figure 2 presents the average UE throughput at different number of SCs per cluster at different traffic loads. The optimum number of deployed SC per hotspot varies with the traffic load. With the increase in traffic load, we can note that there is a need for more SCs to provide more resources to serve UEs while the overall performance of the network decreases. At low traffic loads, resources of small number of SCs are enough to fulfill UEs demands and the dominant factor of performance is the inter-SC interference that needs to be reduced. At a given constant traffic load, the optimum density is the one that achieves a balance between inter-SC interference and available resources for serving UEs. When performance is very close for a range of SC densities, like the case of low traffic where 2-6 SCs can provide almost same performance, the choice becomes mainly dependent on cost and the least density is the most attractive choice.

IV. HIGHER ORDER MODULATION & TRANSCIEVER IMPAIRMENTS

A. 256QAM

In LTE and LTE-Advanced releases (Rel.8-11), QPSK, 16QAM and 64QAM have been the main Modulation and Coding Schemes (MCSs) [13]. With the introduction of HetNets and SCs, UEs associated with SC nodes were shown to have better channel characteristics and lower propagation losses. Hence, higher order modulations schemes like 256QAM can be utilized to improve performance [14][15]. 256 QAM constellation points can be defined as:

$$S_{xy} = \sqrt{\frac{1}{170}}\left(a_x + \jmath\, b_y\right) \tag{4}$$

Where

$$\{a_x\,, b_y\} = \begin{bmatrix} -15{,}15 & -13{,}15 & \dots & 15{,}15 \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ -15,-15 & -13,-15 & \dots & 15,-15 \end{bmatrix} \tag{5}$$

We used link level simulations to produce an LTE physical layer abstraction table with 10 additional MCSs of multiple coding rates and their corresponding TBSs to be inserted in the SLS. These MCSs are being picked when reported SINR in feedback exceeds 20 dB [15]. Figure 3 shows the spectral efficiencies of the added MCSs to support 256QAM in the SLS which is higher compared to all MCSs of lower modulation order [15].

B. Transmitter Impairments

Transmitter includes many circuit parts that cause imperfections in the transmitted symbols. The main sources of these imperfections are the transmitter filter and the clipping and non-linearities of the power amplifier [16]. Thus, there is a deviation of the real transmitted symbol compared to ideal transmitted symbol. The percentage of this deviation with respect to transmission power is known as the Transmitter Error Vector Magnitude (TX-EVM). These imperfections are usually modeled as a zero mean additive white Gaussian noise at the transmitter with variance σ^2_{tx} [16].

$$\sigma^2_{tx} = \epsilon_{tx} * P_t \tag{6}$$

where, P_t is the average transmitted power and ϵ_{tx} is (TX-EVM%)^2

Since TX-EVM noise is applied at the transmitter side, it experiences the fast fading channel like the transmitted signals.

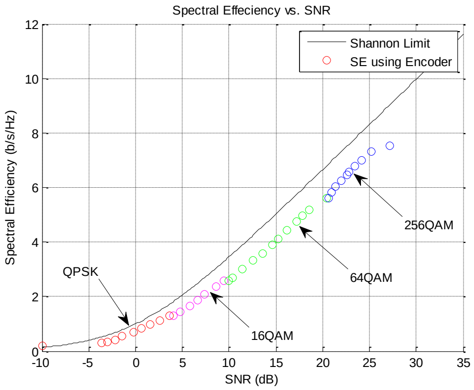

Figure 3. Spectral Efficiency of 256QAM MCS

C. Receiver Impairments

Receiver circuitry causes imperfections in symbols decoding as well. The receiver impairments causing factors are mainly the receiver local oscillator phase noise, receiver dynamic range, I/Q imbalance, carrier leakage and carrier frequency offset [16]. The receiver impairments are expressed in the value of Receiver Error Vector Magnitude (RX-EVM). RX-EVM is the percentage of deviation of the real received symbols compared to the ideal received symbol assuming perfect receiver. It is a noise that does not carry channel fading characteristics but it is proportional to the average received power. RX-EVM is modeled similar to TX-EVM as a zero mean additive white Gaussian noise at the receiver with variance σ^2_{rx} [16]

$$\sigma^2_{rx} = \epsilon_{rx} * P_r \tag{7}$$

where, P_r is the average received power and ϵ_{rx} is (RX-EVM%)^2

Both TX-EVM and RX-EVM have their negative effect on the final received signal (y) at a given UE:

$$y_k = \sqrt{\propto_k}\; H_k W_k \left(x_k + n_{tx}\right) + \sum_{i=1}^{I}\left(\sqrt{\propto_i}\; H_i W_i x_i\right) + n + \sqrt{\propto_k}\; n_{rx} \tag{8}$$

The SINR (γ) is reduced by adding to the interference and noise part in the denominator as shown

$$\gamma = \frac{\propto_k \left\|\sum_{n=1}^{N_t} H_k W_k(:,n)\right\|^2}{\sum_{i=1}^{I}\left(\propto_i \left\|\sum_{n=1}^{N_t} H_i W_i(:,n)\right\|^2\right) + \sigma_n^2 + \sigma_{n_{tx}}^2 \left\|\sum_{n=1}^{N_t} H_k W_k(:,n)\right\|^2 + \propto_k \sigma_{n_{rx}}^2} \tag{9}$$

n_{tx} and n_{rx} are the noise modeling transceiver impairments.

Utilizing higher order modulations such as 256QAM, tolerable imperfections at the transmitter and receiver are reduced since the distance between constellation points are shorter. For example, in 64QAM modulation, TX-EVM is assumed to be 8% [8]. While for 256QAM modulation, TX-EVM is assumed in the range (3% - 6%) [8]. There is no determined value for RX-EVM but in most of research they are assumed in the same range of values of TX-EVM or less (1.5% - 4%) [8].

Transceiver impairments limit the performance of the system so they should be considered while evaluating the throughput gains due to enabling higher order modulation schemes such as 256QAM.

V. PERFORMANCE EVALUATION RESULTS

To evaluate the performance enhancement due to the application of 256QAM, a HetNet with one cluster of 4 outdoor SC nodes is simulated in the SLS with the same simulation parameters described in section II. 256QAM modulation is provided by SCs only. MCNs do not need to support 256QAM since macro channel conditions do not allow notable utilization of higher order modulation and 64QAM is sufficient.

The downlink data traffic is modeled using a bursty FTP traffic model 1. The performance metric for evaluation is the average per user throughput for SC associated UEs (Two thirds of UEs in most cases) who are candidates to utilize 256QAM and the average per user throughput for all UEs. The throughput was calculated in two cases, Case 1 with no impairments at transmitter and receiver. In Case 2, both transmitter and receiver impairments are taken into consideration. EVM percentages and traffic parameters are described in Table V. The throughput with 256QAM supported is compared against the throughput with only up to 64QAM supported to quantify the enhancement in all cases in terms of percentage gain at given utilization of resources (Amount of exploited Resource Blocks (RBs) out of all available RBs over the whole simulation time).

Instantaneous SINR CDFs for Cases 1, 2 are shown in Figure 4 and Figure 5, respectively. There is a good potential for 256QAM in Case 1 since about 22-27% of file transfers have enough SINR (SINR > 20dB [15]) and can utilize 256QAM at all simulated traffic rates. It also indicates that with the increase of traffic, SINR decreases and hence less file transfers can occur with 256QAM. For Case 2, the percentage of UEs who have promising channel conditions for file transfer using 256QAM decreases to about 21-23%.

In Case 1 (with no impairments), support of 256QAM by the SCs layer nodes results in average per user throughput gains for UEs served by SCs ranging from 6% to 9% at SC resource utilizations in the range from 6% to 11%. It is worth noting that, as traffic load decreases, throughput and gains tend to increase as shown in Table VI by comparing gains for ($\lambda = 14$) to lower values.

In Case 2 (with both transmitter and receiver impairments), the gains due to the support of 256QAM are reduced. They are ranging from 2% to 3% for SC associated UEs as shown in Table VII. This is expected due to the increase of the modeled deviation in transmitted and received symbols by having impairments at both transmitter and receiver. This is reflected in terms of more noise impacting the system as can be found in (8). So, SINR γ decreases and throughput degrades as can be deduced from (9). Effect of impairments can be seen in Figure 5 where instantaneous SINR is capped at 30 dB [8].

This degradation can also be noticed from comparing absolute values of throughput at different traffic load levels. The absolute throughput at any given traffic load decreases when TX, RX impairments are added. Simulations also shown that impairments also decreases the chances of using 256QAM (256QAM Utilization Ratio) compared to no impairments case as shown in Table VIII

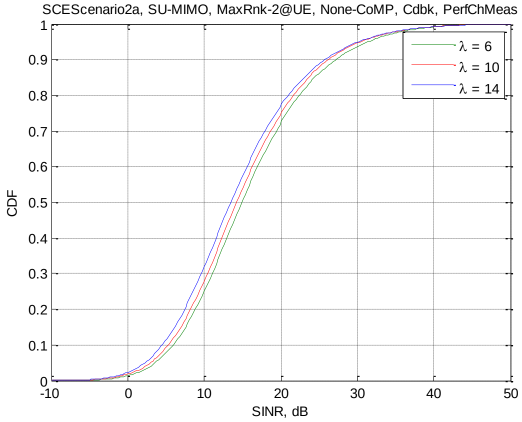

Figure. 4. Instantaneous SINR for SCs UEs in Case 1

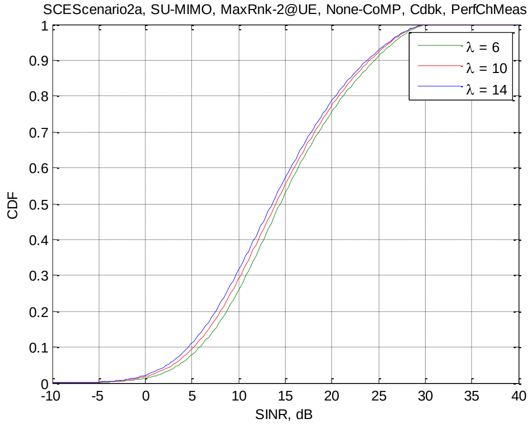

Figure 5. Instantaneous SINR for SCs UEs in Case 2

TABLE V. PERFORMANCE EVALUATION PARAMETERS

Parameter	Value
Traffic Modeling	FTP Traffic Model 1 ($\lambda = 6{,}10{,}14$)
TX-EVM	8% for Macrocell 3% for SCs
RX-EVM	1.5%
Number of SCs	4 SCs/Cluster (1 Cluster/Cell)

TABLE VI. 256QAM PERFORMANCE EVALUATION RESULTS (NO IMPAIRMENTS)

User Arrival Rate (λ) (Sec^{-1})	**Small Cell UEs**		**All UEs**	
	Average User Throughput in Mbps (Gain %)	***% Resource Utilization***	***Average User Throughput in Mbps (Gain %)***	***% Resource Utilization***
6	27.45 **(5.56%)**	5.95%	28.17 **(4.39%)**	7.43%
10	22.61 **(8.75%)**	10.86%	22.75 **(7.67%)**	13.10%
14	18.02 **(7.24%)**	17.05%	17.43 **(5.50%)**	20.08%

TABLE VII. 256QAM PERFORMANCE EVALUATION RESULTS (TX-EVM = 3% & RX-EVM = 1.5%)

User Arrival Rate (λ) (Sec^{-1})	**Small Cell UEs**		**All UEs**	
	Average User Throughput in Mbps (Gain %)	***% Resource Utilization***	***Average User Throughput in Mbps (Gain %)***	***% Resource Utilization***
6	26.58 **(2.79%)**	6.12%	26.42 **(1.60%)**	7.63%
10	21.51 **(3.02%)**	11.20%	21.37 **(3.78%)**	13.62%
14	16.90 **(2.67%)**	17.46%	16.22 **(1.77%)**	20.67%

TABLE VIII. 256QAM UTILIZATION RATIO

λ (Sec^{-1})	**Case 1 No Impairments**	**Case 2 With Tx & Rx Impairments**
6	15.19%	12.62%
10	15.08%	12.05%
14	13.60%	10.67%

From a practical point of view, 256QAM as a higher order modulation technique is promising for SCs with low density of users (especially indoor femtocells). With moving outdoors and increasing UE density, the gains decrease.

VI. CONCLUSION

In this paper, a HetNet with outdoor SCs layer was simulated to study two main aspects. The first aspect is the effect of the dense clusterization of SCs in a hotspot of 70m radius on throughput and performance. We found that the optimum number of SCs for deployment for tolerable level of inter-SC interference and maximized performance depends on traffic. For low traffic, it is 2-4 SCs while we need 6 SCs for medium and high traffic. It was found that with the increase in traffic rate, more SCs are needed to provide more resources and handle UEs requests. On the other hand, at low traffic rates, inter-SC interference is dominant and the needed number of SC decreases. Another factor affects decision when the performance is constant over a range of cluster densities which is cost and least density in the range is preferred.

The second aspect was to evaluate the performance gains resulting from supporting 256QAM for outdoor SC layer in HetNets. It was found that about 6%-9% average throughput gains per UE could be achieved for SC UEs. While, introducing imperfections at the transmitter and receiver sides leads to a decrease in throughput and performance gains of 256QAM compared to traditional 64QAM. Only 2%-3% increase in throughput occur in this case.

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