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Performance Feasibility of 5G NR Dense-urban HetNet Deployment with Differentiated CSI Acquisition Mechanisms

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A 5GNR-compatible HetNet architecture, where backhaul for the millimeter wave(mmWave) small cells on TDD is provided by Massive MIMO enabled macro cell using FDD duplex in sub-6GHz band is proposed. This presents a unique combination of HetNet approach which is also the cornerstone of the novelty within this system simulation design. Moreover, among the major contributions of this work is (1) demonstration of different CSI acquisition mechanism(s) with respect to comparison between backhaul (static) and non-backhaul (mobile) users in macro cell, and (2) showing feasibility of such HetNet deployment scenario with Massive MIMO-utilizing wireless backhaul to small cells . Whereas the accrued findings, in accordance with the throughput results attained are that:- CSI acquisition at the FDD-based macro layer was improved due to long-coherence time on the backhaul link channel, Wireless backhauling proved to be a useable case given the fact that it would pause only a 47% area capacity loss if the entire HetNet were to be supported by wireless and System performance improvement is recorded as a result of the proposed system layout – wireless backhaul & differentiated CSI acquisition mechanism.

Keywords: CSI; HetNet; massive MIMO; mmWave; sub-6GHz

I. INTRODUCTION

The increasing demand for wireless throughput given a fixed electromagnetic spectrum, can only emphasize the requirement for innovative and scalable approaches that ought to guarantee higher spectral efficiency and overall network performance benefits, as explained by (Marzetta *et al.*, 2016). Moreover, since 5G technology embodies a service-based architecture according to (Noll & Chowdhury 2011); the physical layer configuration and functional setup is very much driven by the deployment scenario and use-case at hand as specified by the 3GPP technical report (3GPP TR 38.913: 2018).

Therefore, research improvements at the physical layer are still key to achieving these sought-after performance benefits and efficient spectrum utilization to bring about an adaptable wireless network that will serve the next generation use-cases. Among such improvements are advances in radio technology brought about by Massive Multiple-input Multiple-output (Massive MIMO) which could simply be defined as a Multi-user MIMO system with very large Base Station (BS) antenna arrays, having M antennas and K users, and characterized by the relation $M \gg K$ according to (Marzetta *et al.*, 2016) . Therefore, such spatial components' relation, is guaranteed to derive higher throughput (Larsson *et al.*, 2014) and improved channel estimation quality per antenna (Björnson *et al.*, 2016). Moreover, Massive MIMO which is a scalable version of Multi-user MIMO is now a fully matured technology with no limitations but an enabling platform to realize intelligent solutions for the cellular network, as comprehensively reviewed and reported by (Björnson *et al.*, 2019). Further to that, Massive MIMO BSs still require accurate CSI for optimal performance; a challenge that could be solved through innovative network planning (deployment approaches) as demonstrated through this works' model

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representation published in (Waidhuba *et al.*, 2019a). On the other hand , functional CSI data mining is a new paradigm; in which case if CSI report data (3GPP TS 38.214 2018) were to be well analysed, it could be used to serve more resource applications on the 5G network.

A. Previous Studies

Work on Network densification, has had sufficient cultivation as a practical measure to enhance spectral efficiency according to (Hosseini *et al.*, 2013), especially where Massive MIMO-based Small Cells (SCs) are overlaid with traditional Macro Cells (MCs). Nonetheless, the necessity for HetNet developments follows from both economical and ecological reasons, as power consumption costs a lot to wireless operators (Chen *et al.*, 2011) – whereby radio frequency equipment(s), and thus the physical layer, are seen to take up almost three quarters of the energy budget (Feng *et al.*, 2013). From this point of view, the HetNet approach would serve to achieve energy efficiency of the mobile wireless network as reported by (Rajoria *et al.*, 2018).

Several ideas have been explored concerning small-cell network densification as reported by (Andrews 2013; Hosseini *et al.*, 2013; Hoydis *et al.*, 2013) and a great amount of the research work dedicated to the development of such network architecture and overcoming the associated drawbacks which are normally based on physical limitations among other propagation related constraints, according to (Shao *et al.*, 2015; Zhang, G *et al.*, 2016). Among challenges associated with the Massive MIMO HetNet scheme, its noted that the interference issues, which are typical of standard HetNets (Lopez-Perez *et al.*, 2011). In order to overcome them (or at least reduce their influence), use of the inverse time division duplex (TDD) mode in the massive MIMO HetNet environment was proposed by (Kountouris & Pappas 2013), (Sanguinetti *et al.*, 2015). An extensive review addressing the potential benefits, constraints, as well as the promising research directions with regard to Massive MIMO based HetNets , was done by (Bogale & Le 2016), and (Busari *et al.*, 2018).

A typical scheme of the HetNet realization combining the low-power BSs and traditional high-power MBS is shown in Figure 1; where, benefits of such a layout are given, including but not limited to the positioning of BSs per their propagation characteristics to improve overall network capacity. Moreover, as reported by (Yang & Quek 2017) SC- based network densification is key to the Next generation Mobile Network (NGMN) requirements, say, the sustained-coverage and higher throughput.

Given the maturity of multi-layered cellular implementations and thus, HetNets. It is now key to focus research on cost-effective deployment alternatives; more so, that the NGMN (5G) demands for agility of Network functions allocation. The wireless backhaul as a key component of HetNet configuration is the answer to this trend. However, the underlying physical layer data transmission is not without critical design constraints that weigh in on the overall network performance; these include (1) Spectrum and energy efficiency-related design decisions, (2) the choice of duplexing mode (operation) :– FDD, TDD or both, that would favour item (1) above, and (3) How to benefit from Massive MIMO system-attributes, in a way that makes best use of item(2) (Feng & Mao 2016).

Actually, the backhaul problem was known earlier because of its importance in Heterogeneous Networks as reported by (Chen *et al.*, 2015). As for Massive MIMO HetNet approach utilizing the mmWave frequencies, several investigations have been carried out pertaining to the maximum achievable capacity, as well as realisable energy efficiency given a wireless backhaul-setting having a finite Small Cell(s)' density, and a threshold was determined which is as reported in (Ge *et al.*, 2016).

The use of full-duplex transmission is, but a timely alternative to make best of use of current advanced antenna technologies (Goyal *et al.*, 2013; Hua *et al.*, 2012), which allows to sufficiently improve the wireless network capacity. Its noted that there are several massive MIMO schemes utilizing the full-duplex regime today, one of such approaches proposed for solving the backhaul problem in massive MIMO was discussed in (Chen *et al.*, 2018); here they sought to address the associated power constraints. whereas authors in (Siddique *et al.*, 2017; Tabassum *et al.*, 2016) also analysed studies towards a full-duplex (FD) small cell; where downlink rate coverage probability of a UE in such network, comprising of in-band and out-band frequency spectrum configurations between SBS and backhaul was modelled. Thus, several works on wireless backhaul in tandem with Massive MIMO implementations, have made use of the radio frequency (RF) spectrum in ways that serve to address deployment-based constraints such as propagation behaviour or site terrain, use-case scenarios, and network infrastructure status. Moreover, the use of FD is seen as an enabler, given recent advances in radio access techniques such as Spatial multiplexing, multiple access, channel coding, and flexible waveforms. In (Lv *et al.*, 2017), an interference coordination framework based on a distributed graph colour algorithm for Massive MIMO HetNet scheme was proposed.

B. Main objective

Contrary to common approaches in literature listed above; an out-of-band spectrum configuration is presented in this work, aimed at realizing a Massive MIMO HetNet with wireless backhaul to a mmWave small Cell layer where the macro Cell is on the sub-6GHz band and micro cell is on mmWave band, and to optimize the archivable performance, given a 5G NR dense-urban deployment scenario as recommended by 3GPP technical specifications. In fact, this paper and work reported extends on preliminary model results as presented in the conference publication (Waidhuba *et al.*, 2019a) where - the complete findings and contributions of the proposed 5G NR physical layer implementations and the associated network heterogeneity are now reported herein. Moreover, - the solution to the backhauling problem and its influence on network capacity is also studied in the proposed system design.

II. MATERIALS AND METHOD

A Massive MIMO HetNet was chosen as an integration of both massive MIMO and heterogeneous network approaches. In the 5GNR context, small cells might be implemented using millimetre wave spectrum, which is well-suited for short-range, near Line-Of-Sight (LOS) propagation; while macro cells would serve users in the sub-6GHz band as shown in Figure 1 below .

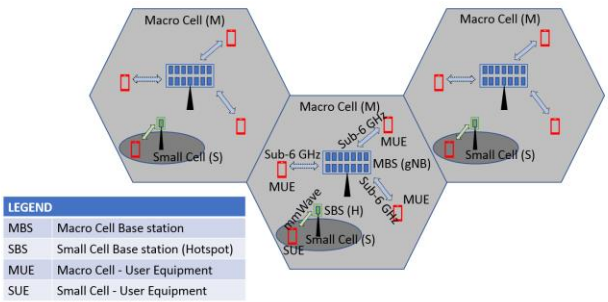

Figure 1. A two (2) - tiered Massive MIMO enabled HetNet with macro Cells and hotspot small Cells

One of the main constraints for large-scale mmWave small cell deployments is availability and cost efficiency of arranging backhaul drops (Ghosh *et al.*, 2012). More so, the choice of backhaul has limitations, say; mmWave based wireless solutions would require Line-of-Sight (LOS) propagation paths, whereas a wired alternative (although offers far-better capacity gains) demands for huge investment on infrastructure (Kela *et al.*, 2016).

Work done by (Tabassum *et al.*, 2016), models a downlink 2-tier cellular network using Poisson Point Processes (PPP), along a wireless backhaul link toward Small Cell BS(s) as established through connector node(CN). And where TDD channel reciprocity is utilized along with linear zero-forcing beam forming. The authors investigate the associated backhaul link performance with respect to the proportioning of small Cells, using coverage probability as a metric. Therefore, a number of design approaches to 5G small cell backhaul design emerged; a lot of them are discussed and compared to (Jaber *et al.*, 2016). - the envisioned 5G NR deployment scenario is a wireless point-to-multipoint backhaul, having macro Cell BS on one side of the link and small Cell BSs on other. This way, the macro BS serves both 'typical' UEs like smartphones, tablets, etc. and 'backhaul UEs' which link to small cells' BS; creating another unique scenario for a Massive MIMO HetNet solution (Feng & Mao 2016), -as shown in Figure 2. The performance of the associated network configuration, that is; its access link and the backhaul, is then analysed using the measured cell throughput and total area throughput. Moreover, as reasonably indicated in (Kela *et al.*, 2016) scenarios with users that exhibit low level mobility (say, small cell tier) in a dense-urban deployment would benefit most from a massive MIMO System implementation which serves to reinforce the significance of the proposed HetNet implementation layout as shown in Figure 2, and Figure 3 which explains the flow of backhaul traffic profile with respect to the HetNet.

A Base Station with M antennas, should obtain channel knowledge correctly and timely; this issue is tackled differently depending on the chosen duplexing mode, as this would determine the required radio resources due to pilot transmission or CSI Feedback load with respect to a given coherence period (T_c). At the same time, since neither duplex mode is without limitations, depending on the nature of deployment setting, say, such as under peak power constraints and noise-limited operations, or interference-limited operations; it would be cost effective to employ both FDD and TDD on the same Massive MIMO HetNet to optimize the realizable performance benefits (net downlink rate, throughput, and spectral efficiency) (Marzetta *et al.*, 2016).

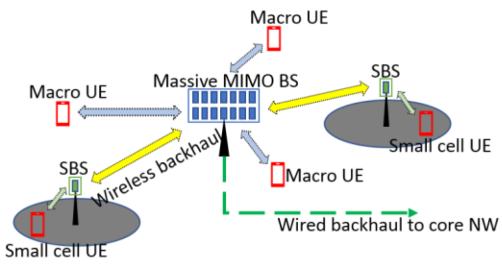

Figure 2. Proposed massive MIMO based HetNet with Wireless backhaul (motivated by (Björnson *et al.*, 2017)

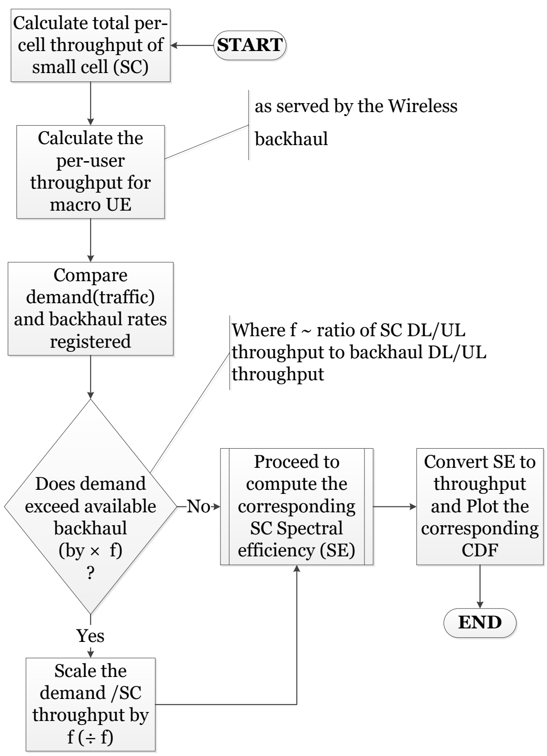

Figure 3. Implementation of the backhaul mechanism

Additionally, (Shen *et al.*, 2017) explored sparsity inspired approaches on FDD and TDD Massive MIMO, respectively given a single cell scenario. In this work, a multi-cell scenario is tackled, and alternatives devised to lower the CSI overhead on the FDD-tier while ensuring improved channel estimate quality on the TDD- tier. Refer to Table 2 on the choice of precoding and combining mechanism(s) along with the channel estimator are listed.

Moreover, an important advantage of the proposed design is the validated feasibility to utilise FDD, and the long coherence time(T_c) of the backhaul link channel since both transmitter (MBS/SBS) and receiver (SBS/MBS) are stationary; therefore the CSI feedback rate is smaller compared to the BS–to-UE communication over fast-fading channels according to (Kela *et al.*, 2016), and (Björnson *et al.*, 2017). A similar approach was taken in (Zhang, C *et al.*, 2016) and realized only on the basis of the statistical CSI to reduce the pilot burden significantly. From Equation (1) extracted from (Björnson *et al.*, 2017), that is;

$$T_c \approx \frac{\lambda}{(4v)} \tag{1}$$

where, v is the velocity of the UE

Therefore, this implies that the channels at the macro layer would need to be estimated less frequently compared to those at the micro layer (small cell tier) due to the accruing difference in frame structure as shown in

Table 1.

Table 1. Coherence Time(T_c) & block(τ_c) computation

Network Parameter	**Sub-6GHz tier (FDD)**	**mmWave Tier (TDD)**
Frame Structure *(Considering Resource block size in 5G NR & associated Numerology)*	Frame dimensions Bc = 180 kHz	Frame dimensions Bc = 1440 kHz,
	Tc = 1ms	Tc = 0.125 ms
	Useful samples per frame τc = BcTc/(1+6.6%) ≈ 169	Useful samples per frame τc = BcTc/1.064 ≈ 169

A. *HetNet Modelling*

The main objectives of this paper were motivated by a massive MIMO practical deployment case study reported by (Björnson *et al.*, 2017), that is; to analyse the performance bounds of a realistic network configuration which targets to represent the latest 5GNR dense-urban deployment scenario as specified in 3GPP technical report by ETSI (3GPP TR 38.913: 2018), for a heterogeneous cellular network

(HetNet) setting. On the other hand, with respect to the basis of the underlying methodology; this work is intended to be reproducible as recommended by (Björnson 2019), hence simulation code pertaining to the results attained herein has been made available via a public repository at (Waidhuba *et al.*, 2019b) under a GNU GPLv3 license.

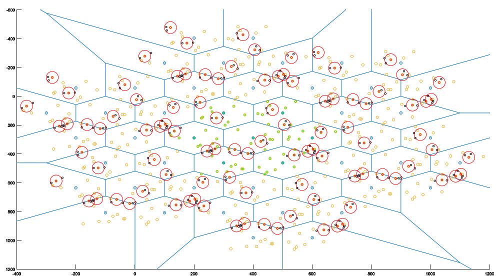

Figure 4. 7-Cell HetNet layout

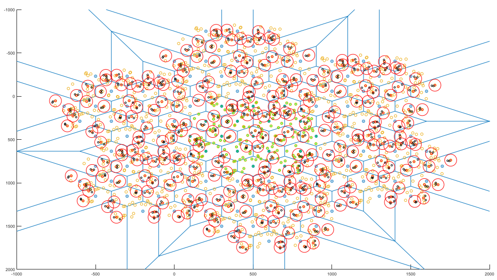

Figure 5. 19-Cell HetNet Layout

Figure 4 and Figure 5; show a 7-cell and 19-cell hex layout with wraparound, respectively, where the blue dots represent macro cells, green dots – macro UEs, red dots with circles – small cells with coverage, black dots – small cell. A fixed number of UEs per macro cell, part of them being 'backhaul UEs' – simultaneously representing backhaul links to small cells, were generated using Quadriga. Summary of target simulation parameters is contained in Table 2. Simulations were performed using Matlab computing software (2018b) - Academic license no. 40717337; relevant channel models were generated using QuaDriGa version 2.0.0-664 from the Fraunhofer Heinrich Hertz Institute as it proved adaptable for the proposed HetNet setup and deployment conditions, as reported in (Borner *et al.*, 2012; Jaeckel *et al.*, 2014, 2017). A CVX Mosek solver from CVX Research, Inc., (Grant & Boyd 2014) was used to address the associated downlink (DL) channel matrix quantization.

Simulation overhead was seen to increase with size of cell setup but resulting in higher optimality. More so, due to the optimization load required per iteration to ensure enough power distribution across the HetNet layers. For example, one (1) setup would take up to one hour while ten (10) setups would take up to thirteen hours of computation time. As a result, in order to be able to present tractable results that would be enough to facilitate the realistic application per the 5G dense urban deployment scenario specified in (3GPP TR 38.913: 2018), the array configuration was varied (the larger the better) to improve on achievable performance as a result of Massive MIMO, the attained results are franked by a compelling discussion on massive MIMO performance given use of TDD and FDD, through work done by (Flordelis *et al.*, 2018). In this paper, the outcomes of such an integrated network configuration are extracted where both duplexing schemes, are used on the same network respectively.

Table 2. Simulation parameters for the targeted 2-tier HetNet for a Dense urban deployment

Parameter	**Value**
Network layout	Hexagonal grid; wrap-around
Number of macro cells	L = 7 and L = 19
Inter-BS distance	200m
Macro UE dropping	K = 10, incl. L_SC = 2 'backhaul UEs'
SC (small cell) UE dropping	K_SC = 2
Channel model (3GPP TR 38.901: 2017)	Urban Macro
	Urban Micro
BS array configuration	Cylindrical array HxVxPol 20×5×1 (M = 100), fully digital beamforming
SC array configuration	Cylindrical array HxVxPol 16×8×1 (M = 128), with 1 RF chain and analog beamforming
BS, SC and UE heights	25m, 10m, 1.5m respectively
Frequency band	Macro layer: sub-6, 2.6GHz
	Small cell layer: mmWave, 28GHz
Bandwidth and Duplexing	Macro layer: 20MHz FDD;
	Small cell layer: 100MHz TDD (SF 44)

Parameter	Value
Frame structure	Macro layer: 1200x 15kHz-wide subcarriers,
	Small cell layer: 1560x 120kHz-wide subcarriers
UE transmit powers	Macro layer: TRP 20 dBm;
	Small cell layer: TRP 23dBm, EIRP 43dBm
Precoding/combining scheme	Macro layer: (DL) D-GOB, (UL) RZF
	Small cell layer: Orthogonal Matching Pursuit (OMP)
Channel estimation mechanism	Minimum mean squared error (MMSE)

B. *Functional CSI acquisition*

Implementation for CSI acquisition mechanism and the subsequent calculation of spectral efficiency is according to (Flordelis *et al.*, 2018); solution called Digital Grid-Of-Beams which provides a simple but efficient way to benefit from Massive MIMO in the FDD band, with feedback (reporting) limited to a set of beams selected by the UE as shown in Figure 6. Moreover, as seen in Figure 7 the estimated CSI is communicated back to the BS over a control channel.

Channel estimation and CSI acquisition for macro layer is different for usual mobile UEs and so-called 'backhaul' UEs (ones which represent backhaul of mmWave small cells) as shown in Figure 7 is achieved by setting up two categories of users (with the help of functionality available in Quadriga channel modeling package): (i) first one consists of mobile UEs, 1.5 m height, with defined track route, speed (20% users have speed of 30km/h), updating channel conditions; (ii) another one is fixed at 10m height with no or slow change in channel conditions.

Comparately, CSI acquisition at the TDD based micro layer (small cell tier) base station (BS), is by estimation from the received pilot signals sent by user equipments (UE), while the downlink channel is automatically estimated as a result of the associated channel reciprocity feature as shown in Figure 8 below.

Additionally, implementation of hybrid precoding/combining for the TDD-based mmWave micro cell layer (small cell tier) was adopted based on the work of (Ayach *et al.*, 2014), which approach decouples the optimizations for the precoding and combinig weights, where it uses Orthogonal Matching Pursuit (OMP) algorithm to derive the precoding weights. Once the precoding weights are computed, the result is then used to obtain the corresponding combining weights. This paper's work defines one RF chain and one data stream, with number of transmit and receive antennas set according to network layout selected to realized the required hybrid beamforming strategy as illustrated in Figure 9.

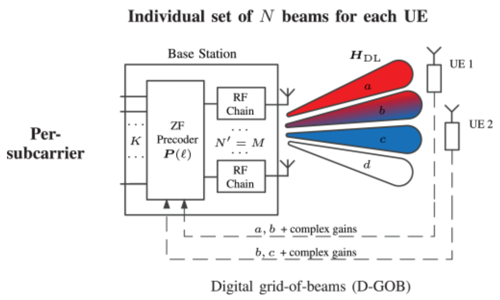

Figure 6. feedback-based FDD beamforming using D-GOB (Flordelis *et al.*, 2018)

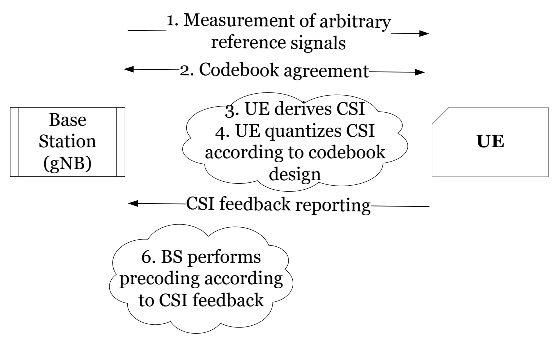

Figure 7. CSI acquisition mechanism at the Macro cell layer

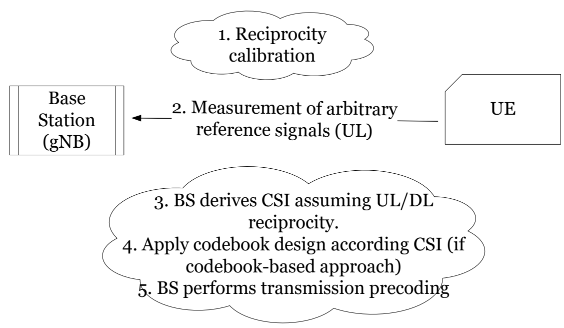

Figure 8. CSI acquisition mechanism at the Micro cell layer

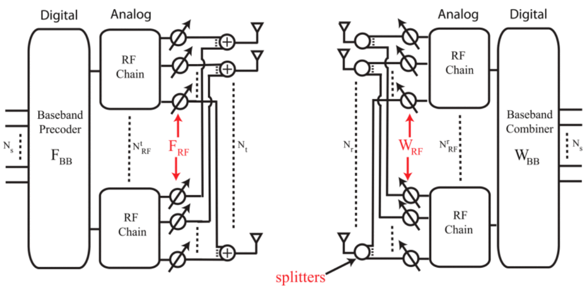

Figure 9. Implementation of hybrid precoding/combining for small cell layer (Ayach *et al.*, 2014)

III. RESULT AND DISCUSSION

The examination of HetNet performance in terms of per-user and per-cell spectral efficiency using CDF plots, and the calculation of the statistics for median/mean/n^{th} percentile values, as well as total area throughput, and comparison with the case of ideal (wired) backhaul to small cells, were performed. Plots in Figure 10 and Figure 11, show maps that provide an understanding of UE densities, location of network elements and UEs, coverage and power distributions, as well as system power levels used. This follows from a heuristic power control policy defined by (Björnson *et al.*, 2017, p. 314 (7.11)).

The performance of simulated HetNet on a per-layer basis (macro Cell UEs and small Cell UEs), for three precoding/combining schemes was tested; regularized zero forcing (RZF) precoding scheme had a higher spectral efficiency than Maximum-Ratio (MR) or multicell minimum mean-squared error (M-MMSE) for both layers (Waidhuba *et al.*, 2019a). The throughput results at the small Cell layer, were higher than those attained at the macro Cell, due to the larger mmWave bandwidth and the associated smaller cell radius, for all precoding schemes.

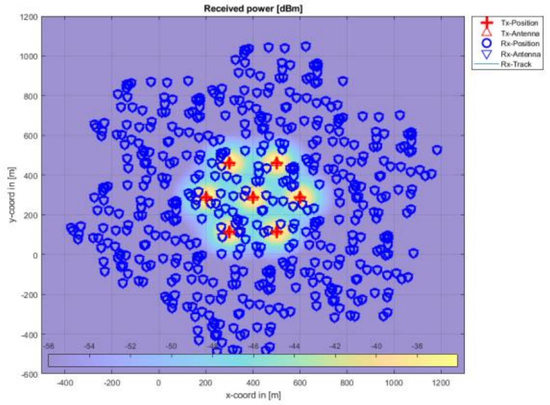

Figure 10. Downlink (DL) received power distribution for macro Cell(MC) layer having 7 cells

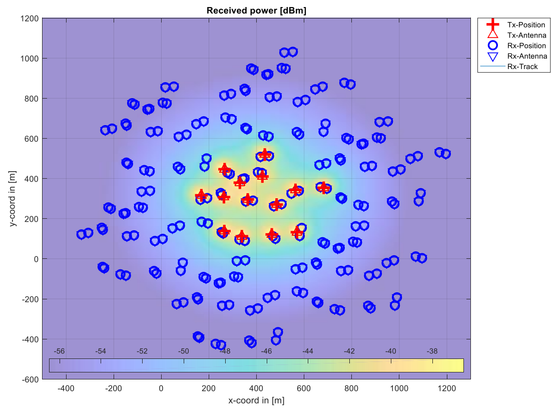

Figure 11. Downlink(DL) received Power distribution for small Cell(SC) Layer having 14 cells (2 SC: 1 MC)

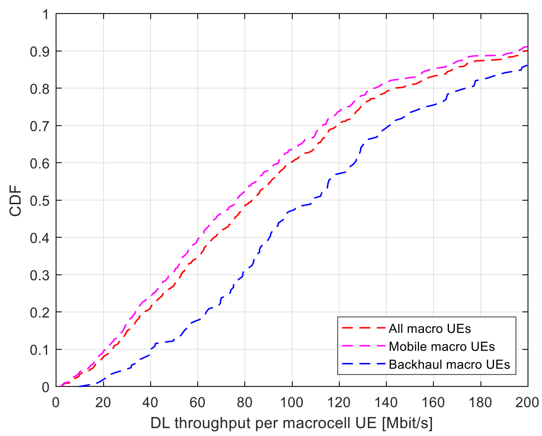

Figure 12. CDF of DL throughput of Macro Cell UEs

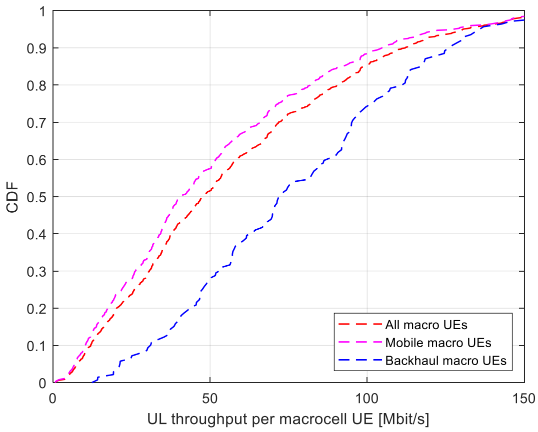

Figure 13. CDF of UL throughput of Macro Cell UEs

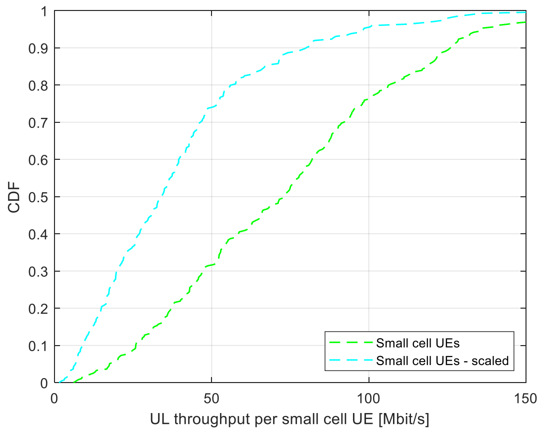

Figure 15 CDF of UL Throughput of Small Cell UEs

Figure 12 and Figure 13 show the results for user throughputs of the macro layer - indicate that fixed, ‘backhaul’ UEs show consistently higher throughputs than mobile UEs, both for DL and UL, which proves - that it is possible to leverage higher CSI acquisition and channel estimation accuracy of fixed Massive MIMO users (calculated MSE of channel estimation for our simulations is ~4 times higher for mobile users than for ‘backhaul’ ones, - (rewrite this sentence) - Two Figure 14 and Figure 15 show the CDFs for user throughputs for the small Cell layer -- which represent the original demand in small cells, and another (“scaled”) showing small cell UE throughputs when -scaling them down considering the available wireless backhaul capacity of the proposed scheme.

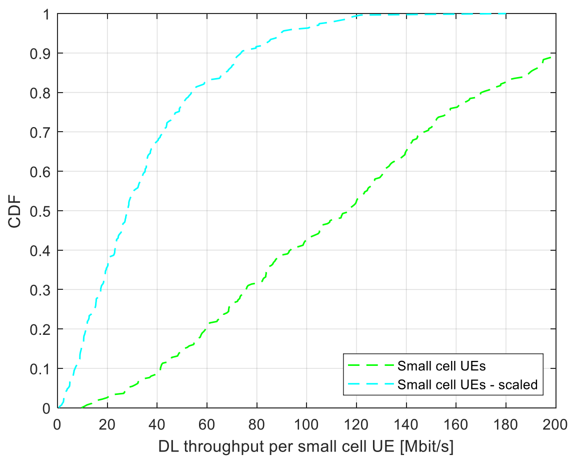

Figure 14. CDF of DL throughput of Small Cell UEs

Table 3 shows that using wireless backhaul restricts median DL throughput from 116Mbit/s to 28Mbits/s, and median UL throughput from 73Mbit/s to 34Mbit/s. Also, one can note that share of small cells which had enough backhaul capacity to handle demand without scaling is 22%, while total capacity loss due to scaling (thus, using wireless backhaul instead of wired drops) is around 47%.

Table 3. HetNet performance in terms of throughput

No.	Type of UE	Median DL [Mbit/s]	Median UL [Mbit/s]
1.	Macro: all UEs	83.07	47.61
2.	Macro: non-backhaul UEs	76.37	40.87
3.	Macro: backhaul UEs	108.49	72.18
4.	Small cell UEs	116.33	72.70
5.	Small cell UEs: scaled	28.07	33.54

Table 4. HetNet performance with respect to target KPIs

No.	KPI	Value
1.	Share of SCs with sufficient backhaul without scaling, by DL	22.14%
2.	Share of SCs with sufficient backhaul without scaling, by UL	22.14%
3.	Share of SCs with sufficient backhaul without scaling, by DL & UL	12.86%
4.	Total capacity loss in DL	47.68%
5.	Total capacity loss in UL	47.08%
6.	MSE of channel estimation, backhaul UEs	1.4e+03
7.	MSE of channel estimation, non-backhaul UEs	5.2e+03

The calculations of the total capacity loss (TCL) and the MSE of Channel Estimation were performed using the following formula-:

$$TCL = \frac{1 - sum\ demand\ in\ Small\ Cell\ (SC)}{sum\ backhaul\ capacity} \quad (2)$$

For the MSE Calculation; the channels in question, are assumed to be correlated Rayleigh fading using the MMSE estimator. Where;

$$MSE\ of\ Channel\ Estimation = tr\left(\begin{matrix} Estimation\ error \\ correlation\ Matrix \end{matrix}\right) \quad (3)$$

Moreover, according to results shown in Table 4, this is indicative of the estimation quality; where the smaller the value, the better. From Figure 16, Median macro cell throughput is 919 Mbit/s in DL and 498 Mbit/s in UL; whereas, for small cells in Figure 17, - both the original and scaled cell throughputs:- original median demand is 213 Mbit/s in DL and 133 Mbit/s in UL, whilst the scaled-median demand became 100 Mbit/s in DL and 70 Mbit/s, respectively.

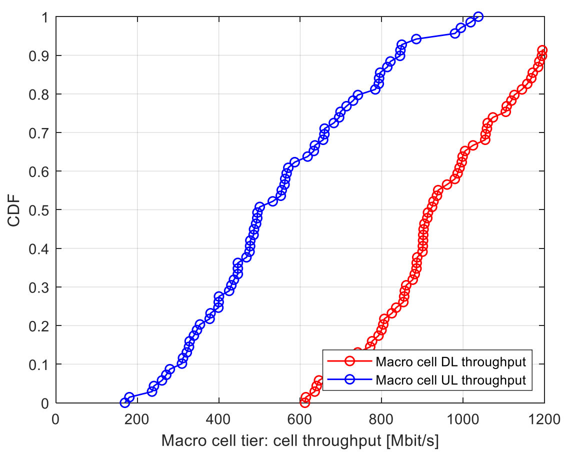

Figure 16. CDF of Macro Cell tier throughput in Mbit/s

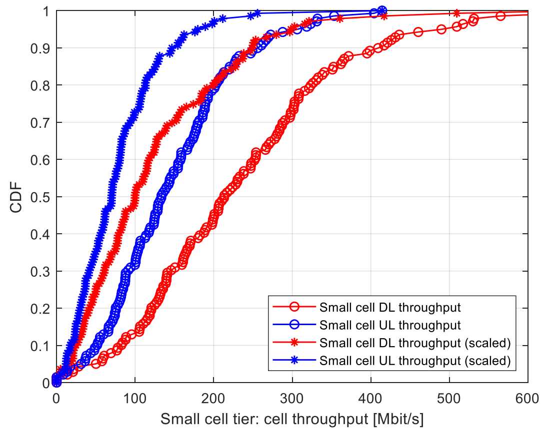

Figure 17. CDF of Small Cell tier throughput in Mbit/s

Table 5. Median, Average Cell throughput (statistics) [Mbit/s]

No.	Type of Cells	Median DL	Median UL	Average DL	Average UL
1.	Macro Cell	918.78	497.76	957.03	551.24
2.	Small Cell (SC)	213.36	133.35	231.61	144.75
3.	SC(scaled)	99.81	70.01	123.63	77.786
4.	SCs: capacity loss, %	53.22	47.5	46.62	46.26

Table 5 shows the calculation of statistics for cell throughput. Here the capacity loss due to wireless backhaul is calculated, based on median or average cell throughputs. In terms of total area throughput (see Table5), area capacity loss is only 15% in DL and 16% in UL, with the total area throughput even with wireless backhaul comprising impressive 348 Gbit/s/km2 in DL and 204 Gbit/s/km2 in UL.

Table 6. Area throughput (statistics)

DL/UL	(original), Gbit/s/km²	(scaled), Gbit/s/km²	Area capacity loss, %
DL	409.9901	347.6478	15.2058
UL	242.7049	204.0408	15.9305

Area throughput (AT) is used as a performance metric here in Table 6, to demonstrate the impact of increased Spectral efficiency (SE) as a result of the proposed Massive MIMO based HetNet implementation. That is;

$$AT = B \times D \times SE \quad (4)$$

where B[Hz] is the bandwidth, D [cells/km2] is the average cell density, and SE [bit/s/Hz/cell] is the Spectral Efficiency per cell.

IV. CONCLUSION

A system-level simulation of 5GNR Massive MIMO based HetNet with Wireless backhaul to small cells is studied, where an inter-working between two layers of HetNet were successfully introduced by virtue of their different functional CSI requirements. Hence, feasibility of the proposed network architecture with respect to a dense-urban deployment scenario has been positively ascertained, through the performance results that show appreciable throughput levels per UE, Cell layer, and Total area of the HetNet, which translates to overall improved spectral efficiency.

A promising direction for future research could be further improvements for Massive MIMO algorithms designed for FDD operation, both for mobile users (fast fading channels) and fixed users (slow fading channels).

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