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## Research Article

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# Performance measurement of small-cells deployed under a heterogeneous network: an analysis of the co-existence of small-cells with the macro-cell in 5G NR

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**Abstract** – Advancements of cellular networks such as 4G and 5G proposed the collaboration of small-cell technologies in mobile networks and constructed a heterogeneous network (HetNet) for collaborative connectivity. There are many benefits of small-cell-based collective communication such as the increase of device capability in indoor/outdoor locations, enhancement of wireless coverage, improved signal efficiency, lower implementation costs of gNB (Next-generation Base Station introduced in 5G), etc. The integration of small-cells by deploying low-power BSs (base stations) in conventional macro-gNBs was investigated as a convenient and economical way of raising the potentials of a cellular network with high demand from consumers. The fusion of small-cells with macro-cells offers increased coverage and capacity for heterogeneous networks. Therefore, the research aimed to realize the performance of a small-cell deployed under a macro-cell in a two-tier heterogeneous network. The research first modified the reference equation for measuring the received power by introducing the transmitter and receiver gain. The paper then measured the SINR, throughput, spectral efficiency, and power efficiency for both downlink and uplink by empirical simulation. The research further enlisted the notable outcomes after examining the simulation results and discussed some relevant research scopes in the concluding sections of the paper.

**Keywords** – 5G, Small-cell, Macro-cell, HetNet.

## 1. Introduction

Propelled by the explosion of increasingly evolving gadgets and the introduction of new services, the mobile and wireless network traffic is increasing geometrically each year and this increment is continuing persistently. From 2010 to 2025, a 1000-times rise in data traffic is predicted with a further 10 to 100-times rise in 2020 to 2030, as per projection and statistical research conducted by the International Telecommunications Union (ITU) [1], [2]. Several advanced technologies are needed to counter this rapid increase in data traffic to satisfy constantly growing data offloading traffic and network demand. As a result of the transition of the cellular network to LTE and 5G NR, the network has emerged as a multi-tier or multi-level network that incorporates a traditional mobile network with many low-powered base stations (e.g., small-cells). Large-scale deployment of small-cells in such HetNets, including pico-cells and femto-cells underlaid inside a macro-cell network, is indeed

one of the promising strategies for addressing the growing wireless traffic [3].

According to the statistics, approximately 67% of the cellular operators have already deployed indoor small-cells (femto-cells), and the deployment of all types of small-cell (e.g. pico-cells, femto-cells) increased from 4.3 to 36.8 million in the year 2015. More than 40,000 outdoor small-cells have already been installed by the end of 2016 [4], [5]. A small-cell BS (SBS) is a cost-effective, low-power radio transmission system built to cover a short coverage region. It can be implemented in plug-and-play mode, having the capability of self-configurations according to the required transmission parameters and does not require sophisticated maintenance [6], [7].

Moreover, small-cell networks reflect a change of approach from conventional central macro-cell BSs to a more self-organized model in which small-cells are used in all considerable environments, including both indoors and outdoors, in combination with existing macro-cells. However, a new set of critical architectural problems are emerging from the coexistence of various types of network equipment with different requirements on the same scale. These primary issues must immediately be tackled so that the promised advantages of small-cell solutions are completely achieved [8].

Small-cells have shorter coverage areas and significantly less transmission power to provide network services to their associated UEs with greater service efficiency (QoS) and higher data rates. Nevertheless, the spontaneous deployment of a dynamic collection of small-cells within HetNets complicates resource management techniques; because multiple tiers of small-cell base stations, e.g., the femto-tier and pico-tier, respectively, have distinct transmission characteristics. The macro-cell base stations (MBSs) are usually deployed to offer wide coverage and broadband connectivity to the user equipment (UE) through high power transmission [9], [10]. Comparatively, within a shorter range, pico-cells operate with a licensed radios spectrum having medium power of transmission power and offload data traffic from the macro-cell in hotspot coverage areas.

To ensure efficient performance of small-cells deployed under a heterogeneous network (with respect to allocated network resources) prior measurements and analyses considering several network performance criteria are necessary.

The paper presented research that represents the SINR, throughput, spectral efficiency, and power efficiency

performance of a small-cell (outdoor) deployed under a macro-cell.

The interesting thing is that the research performed in this paper is based on such formulas that are unique in terms of the performance measurement of small-cell (the formulas previously utilized to analyze communication link rather than small-cell or HetNet). Fig. 1 shows the considered two-tier heterogeneous network formed by seven small-cells operating under one macro-cell.

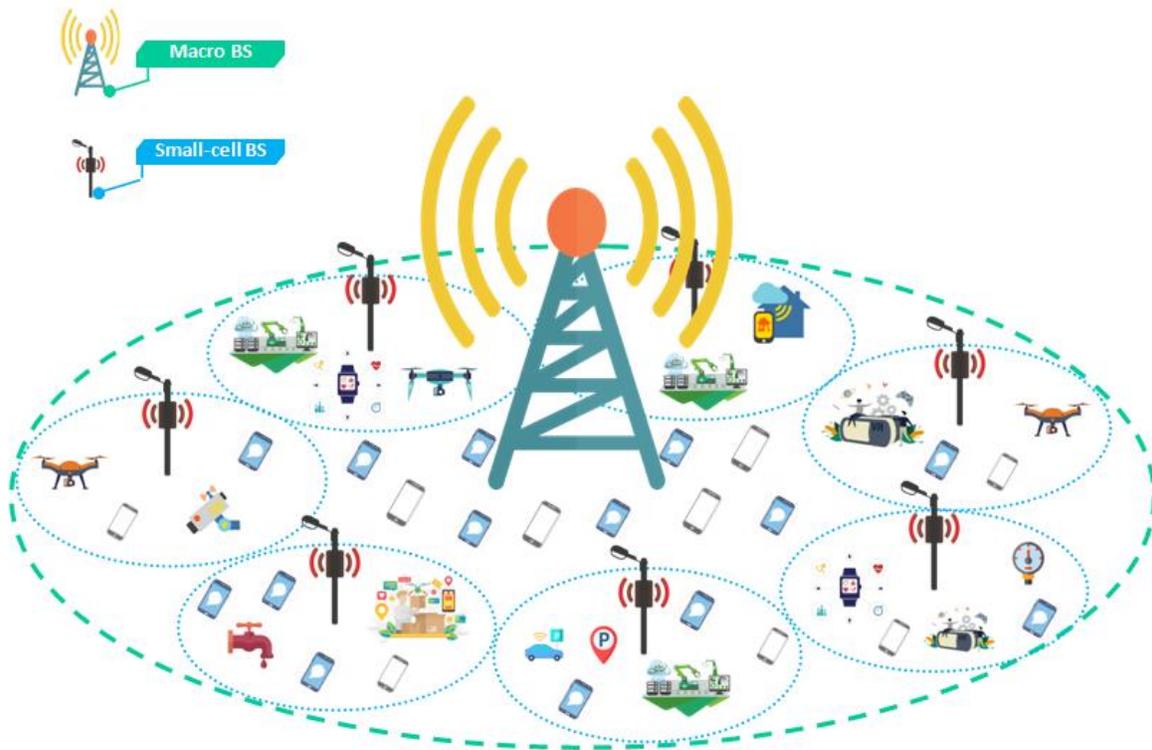


Fig. 1: SBSs deployed under an MBS in a two-tier HetNet

## 2. Related Works and Contributions

In this section, the paper has analyzed several pieces of research previously performed on the deployment of small-cell in a heterogeneous network. It mainly focused on the performance of small-cell deployed under the macro-cell with respect to interference management (from macro-cell and small-cell tier), corresponding throughput, and spectral efficiency.

The research of Ramos et al. [11] explores the average SINR and the throughput of 5G Small-cell HetNet operating at 2.6, 3.5, and 5.62 GHz. Elkourdi et al. [12] considered network throughput as the prime performance parameter to figure out the optimal placement locations for small-cells. Wu et al. [13] in this paper analyzed the deployment of small-cells to meet the data rate requirement of 5G NR utilizing stochastic geometry. A two-tier Hetero-cellular network (HCN) which consists of macro-cells and small-cells is utilized as the network model. Shimodaira et al. [14] also considered network throughput as the

In the following sections of this paper, section 2 describes the related works, literature, and contributions relevant to this work. Section 3 includes models for measurements (equations/formulas). Section 4 included the simulation results with brief discussions. Section 5 includes notable outcomes of the research and future research directions. Section 6 is the concluding section for this article.

prime performance parameter for the deployment of small-cells. Pratap et al. [15] studied the resource allocation approach for spectrum reuse maximization, minimization of interference, and user-level fairness in small-cells for heterogeneous 5G networks. Pak et al. [16] analyzed effective deployment of small-cell with respect to SINR performance. Haija et al. [17] investigated the impact of cooperation of small and macro-cell (SMC) for enhancing the spectral efficiency and network reliability in the case of uplink in a HetNet. Guo et al. [18] proposed a framework to maximize the efficiency (spectral) of the cellular network and to minimize interference generated by the deployment of small-cell. Maltsev et al. [19] considered a cellular network with a few millimeter-wave (mmWave) small-cells under LTE macro-cells. The influence of interactive interference in the mmWave band (57 to 64 GHz) is evaluated. Kazmi et al. [20] analyzed resource allocation to maximize the network throughput of small-cells under the cross-tier interference constraint. Pervaiz et al. [21] have investigated the trade-off between spectral efficiency and

energy efficiency in D2D-enabled uplink transmission in the case of heterogeneous networks.

**Contribution of this Research:** The research has reviewed the aforementioned papers (closely relevant to this research) to gather knowledge about prior works and to find out research gaps. The research interestingly found that most of the article had performed measurements on either uplink or downlink. The notable matter regarding this research is that it has considered both uplink and downlink. Another important point is that the research has modified the reference formula by including transmitter-receiver gain. Moreover, the research has performed measurements considering the SINR, throughput, spectral efficiency, and power efficiency, and all of these measurements altogether in a single article were absent earlier according to the authors' best expertise. These all might be considered as the notable extensions introduced by the research.

### 3. System Model

The research considered a two-tier heterogeneous network (HetNet) where small-cells are laid within the macro-cell network. Considering a geo-location  $\mathfrak{D} \subset \mathfrak{R}^2$  in which wireless user equipment (UE) are situated in a two-dimensional plane. A set  $\mathfrak{M}$  of  $M$  small-cell base stations (SBS) are deployed as terrestrial base stations to serve corresponding UEs. The network traffic in the heterogeneous network is presumed as a full buffer. Contemplating an SBS  $i \in \mathfrak{M}$  is serving its corresponding UEs  $u \in i$ . Let,  $P_i^{ScBS}$  and  $B_i^{ScBS}$  are maximum transmit power and bandwidth per-channel designated to serve the UE. Similarly,  $P_{u \in i}^{UE}$  and  $B_{u \in i}^{UE}$  are transmission power and bandwidth of UE.  $P^{MBS}$  denotes the maximum transmission power of a macro-cell BS [22].

Thereby the received power in terms of downlink (SBS-to-UE) can be calculated using the following formula (Eq. 1),

$$\bar{P}_{r,u \in i}^{UE} = \frac{P_i^{ScBS} G_t G_r \delta_{t,r}}{D_{t,r}^\alpha} \quad (1)$$

where  $G_t$  and  $G_r$  represent the transmitter and receiver antenna gain.  $\delta_{t,r}$  denotes the Rayleigh fading coefficient that follows independent exponential distributions with unit mean e.g.  $\delta_{t,r} \sim \exp(1)$ .  $\alpha$  is the path loss exponent whose value is usually  $\geq 2$ .  $D_{t,r}$  is the transmitter-receiver separation distance in meters. Similarly, the received power in the uplink (UE-to-SBS) can be measured by (Eq. 2),

$$\bar{P}_{r,i}^{ScBS} = \frac{P_{u \in i}^{UE} G_t G_r \delta_{t,r}}{D_{t,r}^\alpha} \quad (2)$$

Since the received power for the downlink and uplink is derived the SINR can be calculated. The downlink SINR can be measured using the following equation (Eq. 3),

$$\zeta_{u \in i}^{UE} = \frac{\bar{P}_{r,u \in i}^{UE}}{I_i + I_{MBS} + N} \quad (3)$$

where  $I_i = \beta \sum_{j \neq i}^n \bar{P}_{r,u \in i}^{UE}$  denotes the interference received by the UE from other SBSs of the same tier rather than serving SBS  $i$ .  $\beta$  is the adjustment factor or weight-factor valued among 0 to 1.  $I_{MBS} = \frac{P^{MBS} G_t G_r \delta_{t,r}}{D_{t,r}^\alpha}$  denotes the interference received by the UE from the MBS.  $P^{MBS}$  denotes the transmission power of MBS.  $N = -174 + 10 \log_{10}(\text{Bandwidth in Hz})$  denotes the noise power.

Similarly, the uplink SINR can be measured by (Eq. 4),

$$\zeta_i^{ScBS} = \frac{\bar{P}_{r,i}^{ScBS}}{I_i + I_{MBS} + N} \quad (4)$$

Thereby the throughput in terms of the downlink is measured by the following formula (Eq. 5),

$$\mathcal{C}_{u \in i}^{UE} = B_i^{ScBS} \log_2(1 + \zeta_{u \in i}^{UE}) \quad (5)$$

The uplink throughput can be measured by (Eq. 6),

$$\mathcal{C}_i^{ScBS} = B_{u \in i}^{UE} \log_2(1 + \zeta_i^{ScBS}) \quad (6)$$

The spectral efficiency for downlink can be calculated by (Eq. 7),

$$\eta_{u \in i}^{UE} = \log_2(1 + \zeta_{u \in i}^{UE}) \quad (7)$$

The uplink spectral efficiency thereby measured by (Eq. 8),

$$\eta_i^{ScBS} = \log_2(1 + \zeta_i^{ScBS}) \quad (8)$$

The power efficiency for downlink can be calculated using the following formula (Eq. 9),

$$\mathcal{E}_{u \in i}^{UE} = \frac{B_i^{ScBS} \log_2(1 + \zeta_{u \in i}^{UE})}{P_i^{ScBS}} \quad (9)$$

The power efficiency in terms of uplink can be measured by (Eq. 10),

$$\mathcal{E}_i^{ScBS} = \frac{B_{u \in i}^{UE} \log_2(1 + \zeta_i^{ScBS})}{P_{u \in i}^{UE}} \quad (10)$$

The important fact is that the research has modified the formula for received power. This research included the transmitter and receiver gain as well to measure the received power. The reference paper [22] has not included the gain.

### 4. Simulation Results and Discussions

This section of the research presents the empirical measurements based on MATLAB simulation to represent and realize the performance of the small-cell deployed under a macro-cell in a two-tier heterogeneous network. The section thereby includes the simulation results for SINR, throughput, spectral efficiency, and energy efficiency. Table 1 enlists the simulation parameters and values.

Table 1: Simulation parameters and values

Measurements and Parameters	Values
<b>1. SINR Measurement</b>	
<i>1.1. SINR Measurement (Fixed MBS Power and SBS-MBS Separation Distance)</i>	
SBS Power	1 – 6 W
UE Power	0.2 – 2 W
Transmitter Gain (SBS)	8 dB
Receiver Gain (UE)	5 dB
SBS-UE (Tx-Rx) Separation	0 – 100 m
Interfering SBS Power	1 – 6 W (6 interfering SBSs)
MBS Power	100 W
MBS Antenna Gain	15 dB
Considered SBS-MBS Separation	1200 m
<i>1.2. SINR Measurement (Fixed SBS Power and SBS-UE Distance)</i>	
SBS Power	6 W
UE Power	2 W
SBS-UE (Tx-Rx) Separation	50 m
Interfering SBS Power	6 W
MBS Power	10 - 100 W
MBS Antenna Gain	15 dB
Considered SBS-MBS Separation	400 - 2000 m
<b>2. Throughput Measurement</b>	
<i>2.1. Throughput Measurement (Fixed Transmitter-Receiver Separation Distance)</i>	
Downlink Bandwidth (SBS)	1 – 20 MHz
Uplink Bandwidth (UE)	1 – 5 MHz
SBS-UE (Tx-Rx) Separation	50 m
SBS Power	1 – 6 W
UE Power	0.2 – 2 W
<i>2.2. Throughput Measurement (Fixed Power of SBS and UE)</i>	
Downlink Bandwidth (SBS)	1 – 20 MHz
Uplink Bandwidth (UE)	1 – 5 MHz
SBS-UE (Tx-Rx) Separation	0 - 100 m
SBS Power	6 W
UE Power	2 W
* In this measurement the parameters of MBS and interfering SBS are the same as measurement 1.1.	
** For the measurements regarding spectral and power efficiency all the values for corresponding parameters are the same as measurements 1 & 2.	

#### 4.1 SINR

The measurement and analysis regarding the SINR for both downlink and uplink are illustrated in this sub-section. Fig. 2 shows the measurements of downlink SINR with respect to transmitter-receiver separation distance and SBS transmission power.

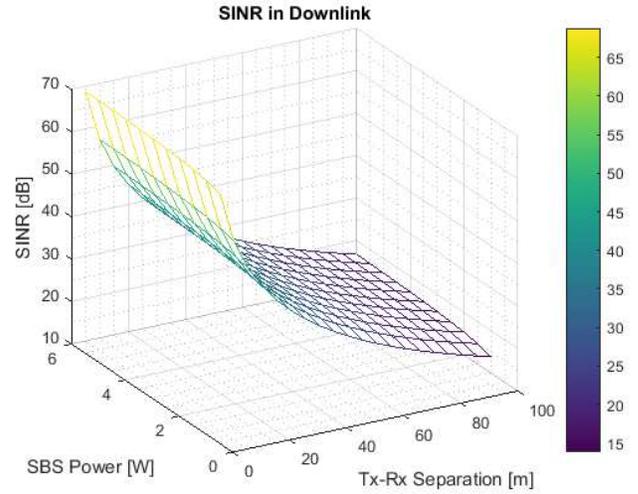


Fig. 2: Downlink SINR

Examining the measurement of downlink SINR the research obtained a maximum of 70 dB and a minimum of 15 dB SINR in the downlink. With respect to the considered power, the downlink SINR only varies approximately 4 dB for maximum to minimum transmission power of the SBS and corresponding transmitter-receiver separation distance.

Fig. 3 shows the measurements of uplink SINR with respect to transmitter-receiver separation distance and UE transmission power.

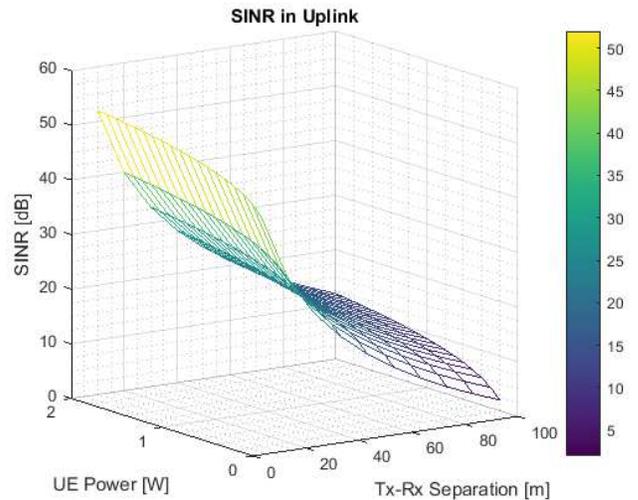


Fig. 3: Uplink SINR

Analyzing the measurement of uplink SINR the research figured a maximum of 52 dB and a minimum of 2.5 dB SINR in the uplink. With respect to the considered power of UE, the uplink SINR varies approximately 10 dB for maximum to minimum power of the UE and corresponding transmitter-receiver separation distance.

Fig. 4 (a), (b) visualizes the same measurements from a different viewing angle for better realization.

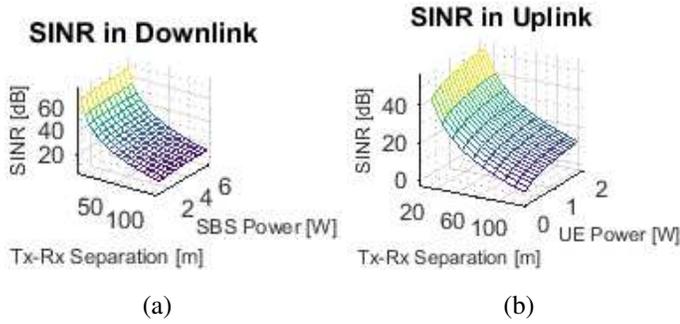


Fig. 4: (a) Downlink SINR, (b) Uplink SINR

Now, the impact of MBS on the SBS varying parameters such as MBS transmission power, distance is represented by the following simulations. Fig. 5 shows the impact of MBS in the downlink SINR.

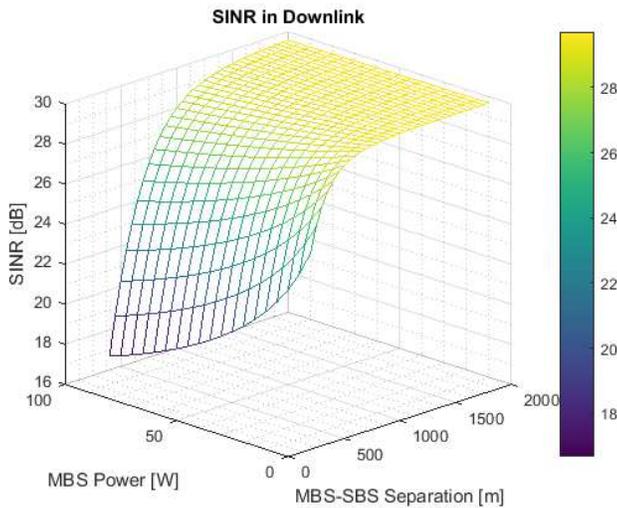


Fig. 5: Downlink SINR

For a shorter separation distance between MBS and SBS, the downlink SINR fluctuates up to 10 dB for maximum to minimum transmission power of MBS. As the MBS-SBS separation distance increases the fluctuation of SINR (in terms of variation of MBS power) gradually decreases. The research also derived that after a certain distance the impact of MBS on the transmission of SBS almost disappears (or negligible impact). In the case of low transmission power (of MBS) the impact of MBS on the SINR decreases within a shorter transmitter-receiver separation distance compared to the high transmission power of the MBS.

Fig. 6 shows the impact of MBS in the uplink SINR.

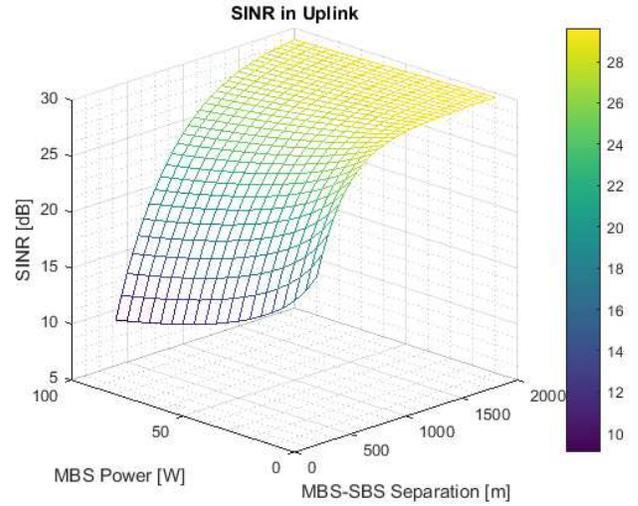


Fig. 6: Uplink SINR

In the case of uplink SINR for a shorter separation distance between MBS and SBS, the uplink SINR fluctuates up to 9 dB for maximum and minimum transmission power of the MBS. As the MBS-SBS separation distance increases the fluctuation of SINR gradually decreases. After a certain distance, the impact of MBS almost disappears (or becomes negligible). In the case of low transmission power (of MBS) the impact of MBS on the SINR decreases within a shorter transmitter-receiver separation distance compared to the high transmission power of the MBS.

#### 4.2 Throughput

This sub-section introduces the measurement of throughput with respect to transmission power (SBS, UE), allocated bandwidth, and transmitter-receiver separation distance. Fig. 7 visualizes the downlink throughput with respect to SBS transmission power and downlink bandwidth for a fixed transmitter-receiver separation distance.

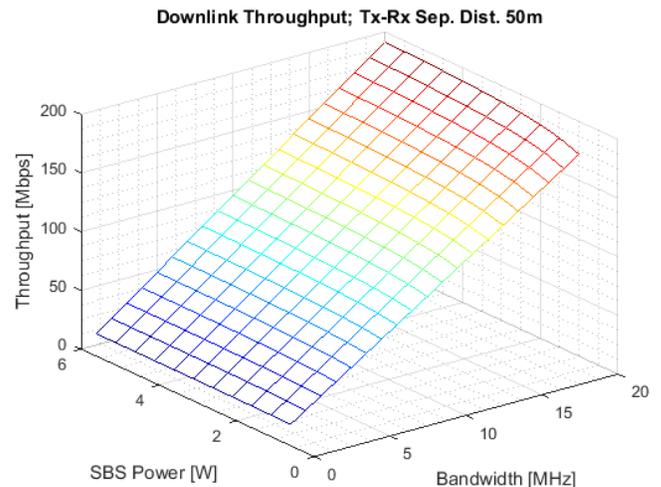


Fig. 7: Downlink throughput

In the case of downlink throughput for 1 MHz bandwidth and from minimum to maximum transmission power of the SBS the throughput varies up to 1 Mbps (8.603 to 9.568 Mbps). For maximum bandwidth (20 MHz) and from minimum to maximum transmission power of the SBS the throughput varies up to 19 Mbps (172.1 - 191.4 Mbps). The measurement is performed considering a separation of 50 m between transmitter and receiver.

Fig. 8 shows the uplink throughput in terms of allocated SBS transmission power and bandwidth for a fixed transmitter-receiver separation distance.

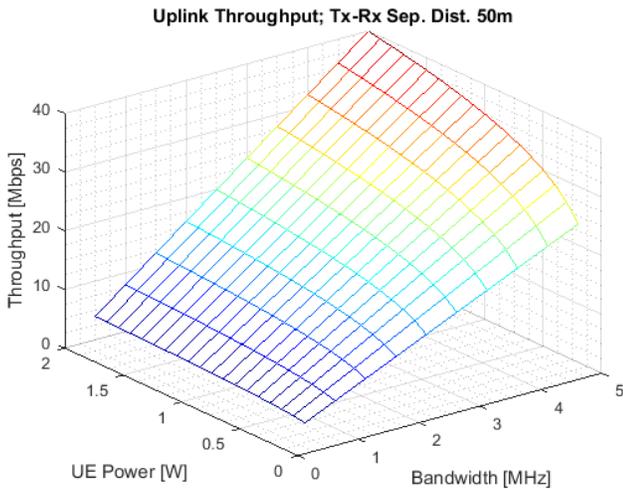


Fig. 8: Uplink throughput

In terms of uplink throughput for minimum (1 MHz) bandwidth and from minimum to maximum transmission power of the UE the throughput varies approx. 1.8 Mbps (2.258 to 3.993 Mbps). For maximum bandwidth (20 MHz) and from minimum to maximum transmission power of the UE the throughput varies approx. 16.4 Mbps (23.58 - 39.93 Mbps).

Fig. 9 visualizes the downlink throughput in terms of varied transmitter-receiver separation distance and downlink bandwidth for a fixed SBS transmission power.

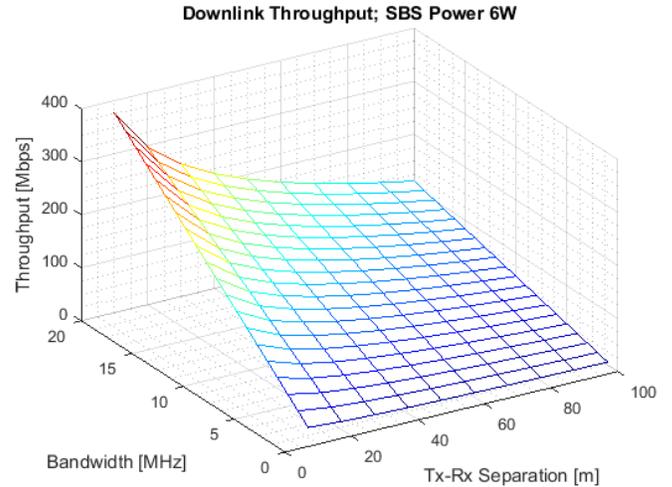


Fig. 9: Downlink throughput

For the shortest transmitter-receiver separation, the network throughput in terms of considered bandwidth highly varies. For 1 – 20 MHz bandwidth, the throughput varies from 18.85 – 377.1 Mbps (approx. 358 Mbps) for the shortest transmitter and receiver separation distance. But with the increment of transmitter-receiver separation distance, this variation of throughput gradually decreases. In the case of the highest transmitter and receiver separation distance, the throughput varies from 5.596 – 111.9 Mbps (approx. 107 Mbps) with respect to bandwidth considered.

Fig. 10 illustrates the measurement of uplink throughput in terms of varied transmitter-receiver separation distance and uplink bandwidth for a fixed SBS transmission power.

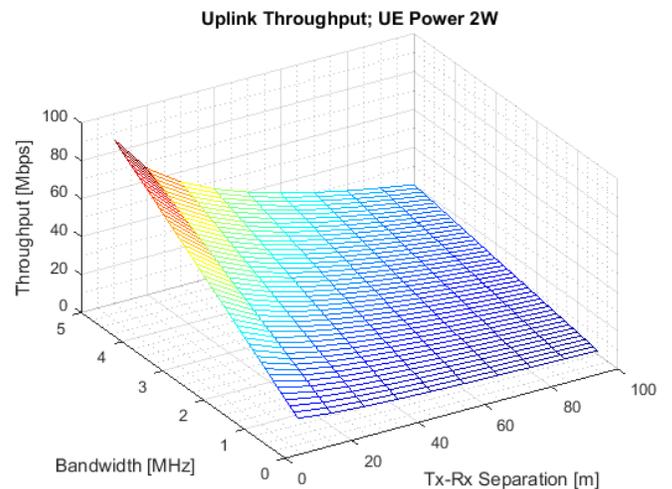


Fig. 10: Uplink throughput

In the case of uplink, the network throughput for the shortest transmitter-receiver separation distance varies highly compared to the maximum transmitter-receiver separation distance. With respect to the allocated bandwidth, the throughput varies from

8.634 – 86.34 Mbps (approx. 78 Mbps) for the shortest transmitter and receiver separation distance. But with the increment of transmitter-receiver separation distance, this variation of throughput gradually decreases. In the case of the highest transmitter and receiver separation distance, the throughput varies from 2.035 – 20.35 Mbps (approx. 18 Mbps) with respect to bandwidth considered.

### 4.3 Spectral Efficiency

In this sub-section, the measurements regarding the spectral efficiency for both downlink and uplink are represented. Fig. 11 shows the downlink spectral efficiency.

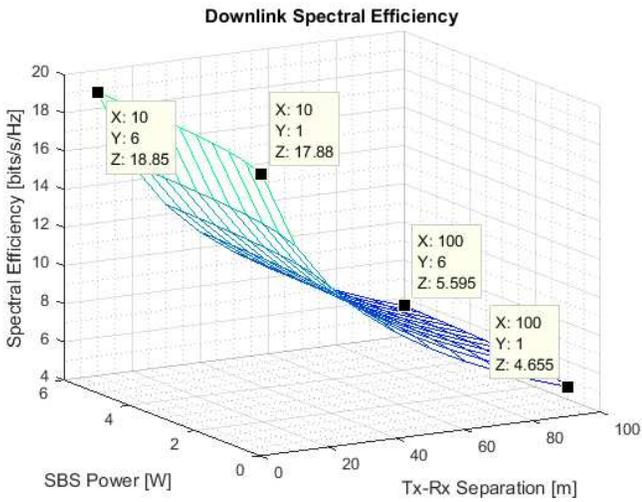


Fig. 11: Downlink spectral efficiency

Fig. 12 represents the uplink spectral efficiency.

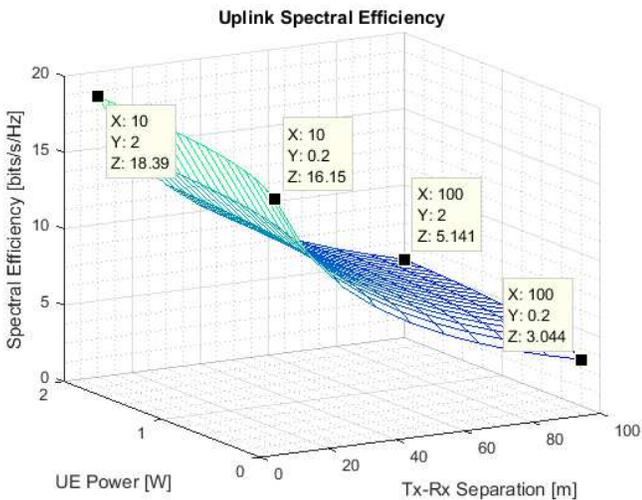


Fig. 12: Downlink spectral efficiency

Fig. 13 (a), (b) visualizes the same measurements from a different viewing angle for better realization.

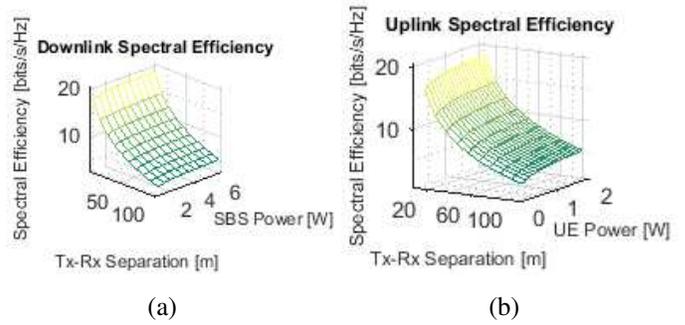


Fig. 13: (a) Downlink spectral efficiency, (b) Uplink spectral efficiency

The research derived that the spectral efficiency for both downlink and uplink is analogous and there is not much difference in the characteristics. But in the case of uplink, the spectral efficiency varies a bit higher than the downlink with respect to considered transmission power and transmitter-receiver separation distance.

### 4.4 Power Efficiency

This sub-section represents the simulations regarding the downlink and uplink power efficiency. First of all, the research performed the measurements of downlink and uplink power efficiency varying the SBS and UE power, allocated bandwidth, and keeping the transmitter-receiver separation distance fixed. Fig. 14 shows the downlink power efficiency.

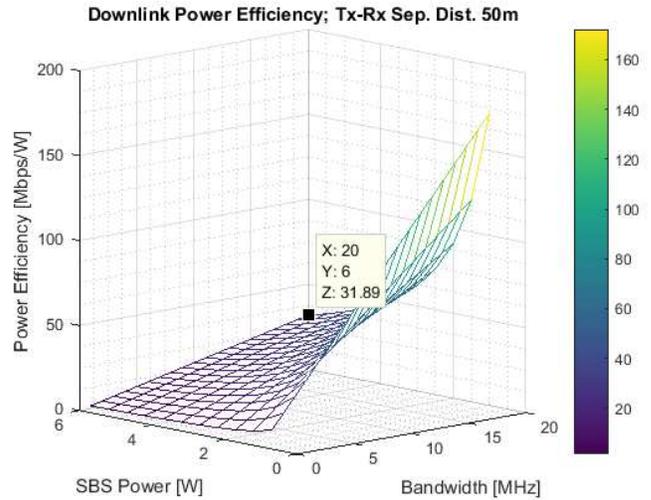


Fig. 14: Downlink power efficiency

Examining the above simulation the research figured out that, with respect to the allocated bandwidth (1 – 20 MHz) for the lowest transmission power of the SBS the power efficiency varies highly approximately 163.5 Mbps/W (8.603 – 172.1 Mbps/W). With the increment of the SBS, power the variation of power efficiency gradually decreases. For the maximum transmission power of the SBS, the variation of power efficiency for the minimum to maximum allocated bandwidth is approximately 30 Mbps/W (1.595 – 31.89 Mbps/W).

Fig. 15 visualizes the downlink power efficiency.

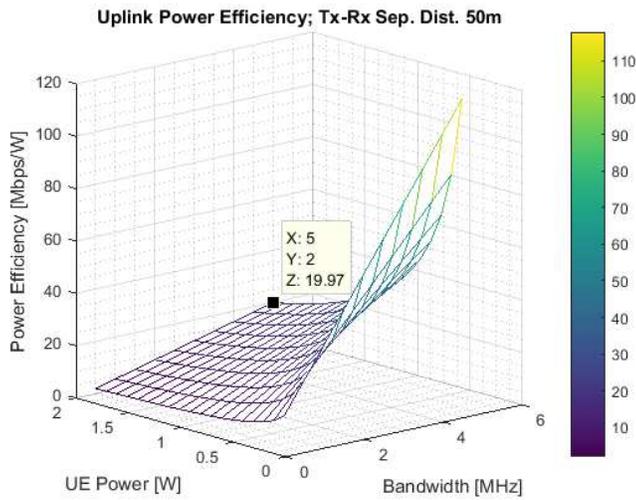


Fig. 15: Uplink power efficiency

In the case of uplink, with respect to the allocated bandwidth (1 – 20 MHz) for the lowest transmission power of the UE, the power efficiency varies highly approximately 106.11 Mbps/W (11.79 – 117.9 Mbps/W). With the increment of the UE power, the high variation of power efficiency gradually decreases. For the maximum transmission power of the UE (considered for this research) the variation of power efficiency for the minimum to maximum allocated bandwidth is approximately 18 Mbps/W (1.997 – 19.97 Mbps/W).

This time, the research performed the measurements of downlink and uplink power efficiency varying the transmitter-receiver separation distance, allocated bandwidth, and keeping the SBS and UE transmission power fixed. Fig. 16 shows the downlink power efficiency.

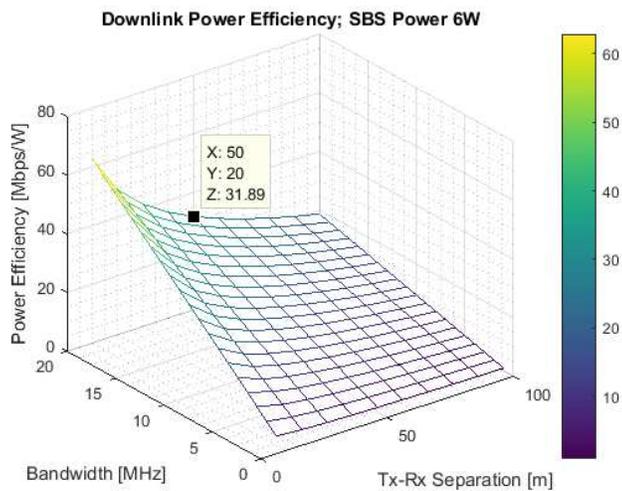


Fig. 16: Downlink power efficiency

With respect to the increment of transmitter-receiver separation distance (0 – 100 m), the power efficiency for the lowest bandwidth varies a little approximately 2 Mbps/W (0.9327 – 3.142 Mbps/W) compared to the maximum allocated bandwidth. For the maximum allocated bandwidth, the variation of power efficiency with respect to the distance (0 – 100 m) is comparatively high approximately 44 Mbps/W (18.65 – 62.85 Mbps/W). Observing these phenomena it can be stated that with the increment of bandwidth the amount of the variation of power efficiency gets increased with respect to the transmitter-receiver separation distance.

Fig. 17 shows the uplink power efficiency.

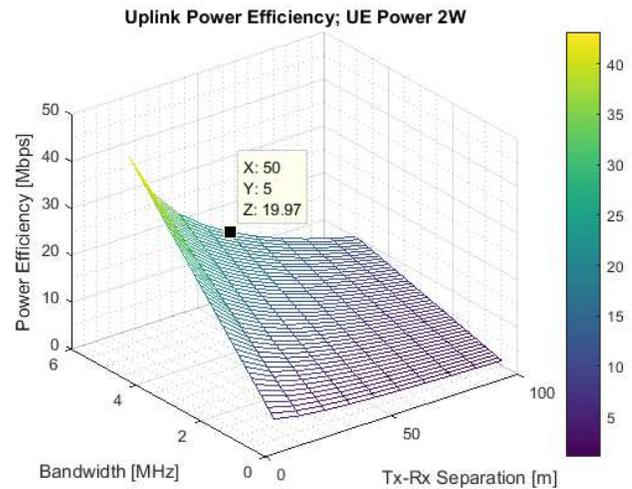


Fig. 17: Uplink power efficiency

In the case of uplink, the variation of power efficiency is analogous compared to the downlink. With respect to the increment of transmitter-receiver separation distance (0 – 100 m), the power efficiency for the minimum bandwidth varies a little approximately 3.3 Mbps/W (1.017 – 4.317 Mbps/W) compared to the maximum allocated bandwidth. For the maximum allocated bandwidth, the variation of power efficiency with respect to the distance (0 – 100 m) is comparatively high approximately 33 Mbps/W (10.17 – 43.17 Mbps/W).

## 5. Research Outcomes and Future Directions

### 5.1 Notable Outcomes of the Research

This sub-section outlines the notable outcomes and findings derived from the research. These are,

**SINR:** The SINR for both downlink and uplink highly varies with the variation of transmitter-receiver separation distance. But it varies in small-scale with the variation of transmission power. In the case of low transmission power (of MBS) the impact of MBS on the SINR decreases within a shorter transmitter-receiver separation distance compared to the high transmission power of the MBS.

**Throughput:** For lower bandwidth, the variation of throughput with respect to the variation of transmission power is comparatively lower (almost negligible) than the higher value of allocated bandwidth. For the shortest transmitter-receiver separation, the network throughput highly varies with respect to the variation of allocated bandwidth (minimum to maximum). With the increment of transmitter-receiver separation distance, this variation of throughput gradually decreases and for the longest separation distance, the variation of throughput is less compared to the shortest separation (with respect to the variation of bandwidth).

**Spectral Efficiency:** The spectral efficiency for both downlink and uplink is analogous according to the findings of this research. But in the case of uplink, the spectral efficiency varies a bit higher than the downlink with respect to considered transmission power and transmitter-receiver separation distance.

**Power Efficiency:** With respect to the variation of allocated bandwidth for the lowest transmission power the power efficiency varies highly. With the increment of the transmission power the variation of power efficiency gradually decreases (for the variation of allocated bandwidth). For the maximum transmission power, the variation of power efficiency with respect to the variation of allocated bandwidth is low. The power efficiency varies on a small-scale with respect to the variation of transmitter-receiver separation distance in terms of low bandwidth. But the power efficiency varies highly with respect to the transmitter-receiver separation distance in terms of high bandwidth.

## 5.2 Research Directions

This segment portrays several research directions on which advanced research and study can be carried out to lead the efficient implementation of small-cells in a heterogeneous network. These are,

- Further assessments may be carried out considering increased transmission power, bandwidth, SBS-UE separation distance, SBS-MBS separation distance, etc.
- Measurements can be performed in further researches considering channel gain (considering formulas mentioned in this research).
- Measurements can be performed considering a 3D deployment scenario.
- Algorithms can be developed considering the formulas of this research for optimal resource allocation.

## 6. Conclusion

The research has characterized the deployment of small-cell under a two-tier heterogeneous network considering the impact of a macro-cell in terms of SINR, throughput, spectral efficiency, and power efficiency. The notable thing of the research is that it has modified the received power formula by including the transmitter and receiver gain. The researchers then measured the SINR, throughput, spectral efficiency, and power efficiency by simulation approaches and briefed the notable

findings from those simulations. The paper also included some further research and enhancement matters for future works. The research pretends to be assistive to enthusiasts, academicians, researchers, and scholars currently engaged in research for the efficient deployment of small-cells in a 5G heterogeneous network.

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