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Analyzing and evaluating the energy efficiency based on multi-5G small cells with a mm-waves in the next generation cellular networks

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Article Info	ABSTRACT
	This paper evaluates the impact of multi-5G small cell systems on the energy efficiency (EE) in a Fifth Generation (5G) of cellular networks. Both the proposed model and the analysis of the EE in this study take into account (i) the path losses, fading, and shadowing that affect the received signal at the user equipment (UE) within the same cell, and (ii) the interference effects of adjacent cells. In addition, the concepts of new technologies such as large MIMO in millimeter range communication have also been considered. The simulation results show that the interference from adjacent cells can degrade the EE of a multi-cell cellular network. With the high interference the number of bits that will be transferred per joule of energy is 1.29 Mb/J with a 0.25 GHz bandwidth and 16 transmit antennas. While, with a 1 GHz bandwidth the transfer rate increases to 5.17 Mb/J. Whereas, with 64 transmit antennas the EE improved to 5.17 Mb/J with a 0.25 GHz BW and 20.70 Mb/J with a 1 GHz BW. These results provide insight into the impact of the number of antennas in millimeter range communication and the interference from adjacent cells on achieving real gains in the EE of multi-5G small cells cellular network.

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1.   INTRODUCTION

The mobile subscriptions grew around 4% between Q1 2016 and Q1 2017, to reach 7.6 billion in Q1 2017; while mobile data traffic grew around 70% in the same period, to reach around 9.7 ExaBytes (EB) per month in Q1 2017; the reason behind this increase is a continuous development in cellular networks and its ability to meet mobile subscriber needs and provide high data speed rates. Accordingly, it is expected that the mobile subscriptions are growing to be 9 billion by 2022, with mobile data traffic approximately up to 71 EB/month, where that 75% will be for mobile video traffic [1]. These challenges have been a crucial step towards the fifth generation of cellular networks, which it is expected to be deployed by 2020 [2].

5G will have to fulfil many requirements, and a critical one is to deliver high network energy performance [3]. High energy performance requires a fundamental change of design principles and implementation practices within the mobile telecom industry. Thus, 5G technology adopts a set of new technologies; a detailed survey on 5G networks has been presented in [4]. The intensive deployment of 5G small cells with mm-waves along with large MIMO will play a significant role in developing 5G cellular network, to overcome the explosive increase in mobile traffic and improve EE of the network, as well as

throughput and a prolong battery life of mobile phone [5]. In 2015, more than 40,000 small cells were deployed [6], and this number is expected to increase in the future upon the deployment of 5G technology [7]. As shown in [8], the number of 5G small cells is anticipated to become four times larger than the number of existing macro sites to cover the same service area. The number of bits transmitted per joule of energy, called energy EE, is used as a performance measure in a green cellular communication system. EE metrics have been discussed in [9, 10]. Since that the performance (the number of bits transmitted) of cellular communication system has been mainly limited by the interference from adjacent cells, as well as by the path losses, fading, and shadowing. Hence, evaluate the impact of multi-cells system on the EE in cellular networks is considered an important issue and need to more investigation, which represents a real cellular network case. Therefore, the key contribution of this paper is a modelling and analyzing EE based on multi-5G small cells of cellular network system to promote the concept of green communication in the next generation network. The concepts of new technologies such as large MIMO (16, 32, and 64 antennas) in millimeter range communication (28 GHz) has been incorporated in the proposed model.

The rest of this paper is organized as follows. Section 2 includes related works. The system model is described in Section 3. The mathematical formulations that considered in this study are given in Section 4. The simulation setup is provided in Section 5. Results and discussion in Section 6. Finally, conclusions are drawn in Section 7.

2.   RELATED WORKS

The fundamental trade-off between energy efficiency in terms of the total number of bits transmitted per Joule per terminal receiving service of energy spent, and spectral efficiency, has been examined in [11, 12]. Authors in [11] have conducted the trade-off for three cases: (i) A reference system with one single antenna serving a single UE; (ii) A system with 100 antennas serving a single UE using conventional beamforming; (iii) A large MIMO simultaneously serving UE. The simulation results shown that a large MIMO system with 100 antennas an efficient in term of energy efficiency. In addition, the SE– EE trade-off is developed in [13] based on the asymptotic SE and the realistic power consumption model for large MIMO system. In the same context, the simulations that have been conducted in [11] shown that each single-antenna user in a large MIMO system can scale down its transmit power proportional to the number of antennas at the BS with perfect channel state information (CSI) or to the square root of the number of BS antennas with imperfect CSI, to get the same performance as a corresponding single-input single-output (SISO) system. Moreover, the relationship between the energy efficiency and spectrum efficiency in a two-cell LTE cellular network, and the impact of multi-antenna on the energy efficiency of cellular network, investigated in [14, 15]. However, these studies were address on the EE issue into the legacy cellular networks; and did not address the issue of EE in the next cellular generation (5G), which it is expected to be deployed by 2020. To continue the vision and promote the concept of green communication and a step towards achieving a green and sustainable 5G cellular networks. This study examined EE issue on multi-5G small cells of cellular network system in millimeter range communication; with consider the interference from adjacent cells, as well as by the path losses, fading, and shadowing.

3.   SYSTEM MODEL

As shown in Figure 1, the BS coverage range is configured as a typical hexagonal cell. The main inter-interference is assumed to be transmitted from two adjacent cells. The system model is used to study the impact of multi-5G small cell systems on the EE of cellular network. The EE, measured in bits per joule, is defined as the total amount data delivered (in bits per second) divided by the total power consumed by the BS (in watts). The main phenomena that affect on the data delivered (bits per second) from BS1 to UE are: (i) the path losses, fading, and shadowing within the same cell (PL_mod_SUI), and (ii) the inter-interference effects of adjacent cells BS2 and BS3 (PI2 and PI3). While, the total power consumed by the BS1 is a directly proportional to the transmission power of BS1 (Ptx_BS1); and the Ptx_BS1 depends on the radius of coverage and the signal propagation fading. More details about the mathematical models will be given in the following section.

4.   MATHEMATICAL MODEL
4.1. Energy efficiency model

Based on the 5G cellular network system model shown in Figure 1, the EE mathematical model as stated below,

$$EE = \frac{R}{P_{tot}^{BS}} = \frac{N_{Ant} BW \log_2\left(1 + \frac{P_{tx\_BS1} + G_1 + P_{L\_mod\_SUI}(R_{c1})}{\sum_{i=2}^{3}\left(P_{tx\_BSi} + G_i - P_{L\_mod\_SUI}(R_{ci}) + N_o\right)}\right)}{N_{TRX}\left(\frac{\frac{P_{tx\_BS1}}{\eta_{PA}} + P_{RF} + P_{BB}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})}\right)} \tag{1}$$
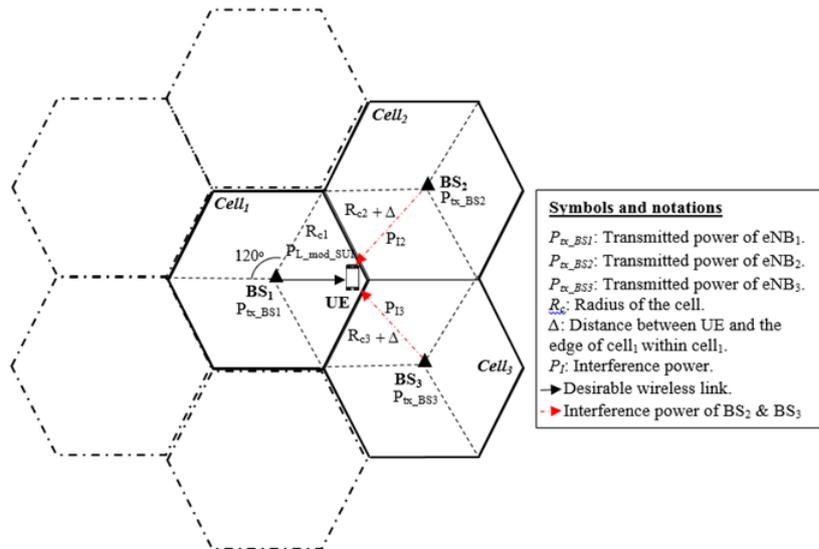

Figure 1. System model of multi-5G small cells

In the EE mathematical model given in (1), the path loss, fading, shadowing, and the interference effects from adjacent cells are considered. However, for ease of understanding, this EE model is simplified and explained in the following paragraphs. In a communication system, the EE, measured in bits per joule, and expressed mathematically [10],

$$EE = \frac{R}{P_{tot}^{BS}} \tag{2}$$

where R is the total data delivered to the UE, and P_{tot}^{BS} is the total power consumed. P_{tot}^{BS} can be calculated by the following formula [16],

$$P_{tot}^{BS} = N_{TRX}\left(\frac{\frac{P_{tx\_BS1}}{\eta_{PA}} + P_{RF} + P_{BB}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{Cool})}\right) \tag{3}$$

where σ_{DC} is the DC-DC regulator losses, σ_{MS} is the main power supply losses, and $\sigma cool$ is the air-conditioner losses. However, by introducing RRHs, feeder losses are avoided by mounting the power amplifier (PA) close to the transmit antenna and using an optical fiber cable. In addition, cooling (air-conditioner) losses are omitted in small BS [16]. P_{tx_BS1} is the output power per transmit antenna, P_{RF} is the radio frequency power, and P_{BB} is the baseband power. Since that the C-RAN architecture is considered in this study, PBB is omitted, because a baseband unit is installed in the central office. η_{PA} is the PA power efficiency, and N_{TRX} is the total transceiver antennas in the site.

4.2. Data rate

As known of Shannon theory, the data rate is directly proportional with the antennas and bandwidth, and logarithmically proportional with SINR [10],

$$R = N_{Ant} BW log_2(1 + SINR) \tag{4}$$

where BW is the bandwidth; and SINR is the signal to interference plus noise ratio, and can be calculated by the following formula,

$$SINR = \frac{P_{rx}}{\sum_{i=2}^{3} P_{I_i} + N_o} \tag{5}$$

where P_I is the interference power of the neighbour BS_2 and BS_3 (which are denoted as P_{I2} and P_{I3}, based on Figure 1, N_o is the noise in wireless channels; and P_{rx} is the received power at UE

4.3. 5G propagation model

The basic propagation model of the received power (P_{rx}) as stated below [17],

$$P_{rx} = P_{tx\_BSI} + G_1 - P_{L_{mod_{SUI}}}(R_{c1}) \tag{6}$$

where G1 is the antenna gain at BS1, and PL_mod_SUI is the path loss model for 5G small cell.

The transmission power of BS1 (P_{tx_BSI}), depends on two main factors: (ii) the required coverage area, and (ii) the surrounding environment (propagation fading). To simplify the model derivation, the macro BS transmission power is normalized as $P_o = 40$ W with the coverage radius $R_o = 1$ km. Similarly, the P_{tx_BSI} with coverage radius Rc1 is denoted by [18],

$$P_{tx\_BSI} = P_o x (\frac{R_{c1}}{R_o})^{\alpha} \tag{7}$$

The mm-wave spectrum is very sensitive to losses due to reflection and diffraction, which greatly depend on the material and the surface. Moreover, reflection and diffraction reduce the range of mm-waves and decrease the ability of a mm-wave signal to penetrate buildings (e.g., brick and concrete) and most solid materials (the attenuations for different materials are given in [19, 20]. In this study, the modified Stanford University Interim (SUI) path loss model ($P_{L\_mod\_SUI}$) for a frequency of 28 GHz for Non-Line of Sight (NLOS) is proposed, as given in (8). This mathematical model (the modified SUI path loss model) is constructed based on extensive empirical measurements [8],

$$P_{L_{mod_{SUI}}}(R_{c1}) = \alpha_{NLOS} x \left(P_{L_{SUI}}(R_{c1}) - P_{L_{SUI}}(do) \right) + P_L(do) + X_o \tag{8}$$

where α_{NLOS} is the mean slope correction factor obtained directly from the NLOS empirical results, $P_{L_{SUI}}(R_{C1})$ is an original SUI model at a distance R_{c1}, $P_{L_{SUI}}(do)$ is an original SUI model at a reference distance do, $P_L(do)$ is the free space path loss in dB at do, and $X\sigma$ is a typical lognormal random shadowing variable with 0 dB mean and standard deviation σ. The original SUI model $P_{L\_SUI(Rc1)}$ for a frequency above 2 GHz is [8],

$$P_{L\ SUI}(R_{c1}) = P_L(d_o) + 10nLog_{10}\left(\frac{R_{c1}}{d_o}\right) + X_{fc} + X_{RX} + X_{\sigma} \tag{9}$$

where,

$$P_L(d_o) = 20Log_{10(\frac{4\pi d_o}{\lambda})} \tag{10}$$

$$n = a - b.h_{TX\_BS1} + \frac{C}{h_{TX\_BS1}} \tag{11}$$

$$X_{fc} = 6\ Log_{10}\left(\frac{f_{MHz}}{2000}\right) \tag{12}$$

$$X_{RX} = -10.8\ Log_{10}\left(\frac{h_{RX}}{2}\right) \tag{13}$$

where λ, Xfc, and XRX denote the carrier wavelength, the correction factors for frequency, and receiver heights, respectively. f_{MHz} is the carrier frequency. h_{TX} and h_{RX} is the transmitter and receiver antenna heights, respectively. The parameters a, b, and c are constants used to model the terrain types encountered in the service area. The SUI terrain type A is considered, with parameters given as a = 4.6, b = 0.0075, and c = 12.6 [8].

The interference power of the adjacent cells that affect the received signal at the UE can be expressed mathematically as,

$$P_I = \sum_{i=2}^{3}(P_{tx-BSi} + G_i - P_{L_{mod_{SUI}}}(R_{ci})) \tag{14}$$

The transmission power of the BS2 and BS3, and the modified-SUI NLOS path loss model are expressed similarly to BS1, as given in the following equations,

$$P_{tx\_BSi} = \sum_{i=2}^{3} P_o x (R_{ci}/R_o)^{\alpha} \tag{15}$$

$$P_{L_{mod_{SUI}}}(R_{ci}) = \alpha_{NLOS} x \left(P_{L_{SUI}}(R_{ci} + \Delta) - P_{L_{SUI}}(d_o)\right) + P_L(d_o) + X_{\sigma} \tag{16}$$

where Δ represents the distance between the UE and the edge of the cell1 within cell1. For example, if the UE is being determined at the edge of cell1, Δ will equal zero

5. SIMULATION SETUP

The simulation layout is given in Figure 1. The modified SUI model at 28 GHz is considered in this study; additional details about the simulation parameters that are used in the present study are given in Table 1. Note that the simulation parameters for both cell2 and cell3 are similar to cell1.

Table 1. List of simulation parameters

Item	Parameter	Acronym	Cell$_1$
Network	Carrier frequency	f_c	28 GHz
	Bandwidth	BW	0.25, 0.5, 1 GHz
	Max. cell radius	R_{c1}	200 m
	Reference distance	d_o	1 m
BS	eNB transmission power	P_{tx_BS1}	1.6 W
			32.04 dBm
	(PA) power efficiency	η_{PA}	38.8 %
	Radio frequency	P_{RF}^{DC}	0.7 W
	Baseband	P_{BB}^{DC}	C-RAN
	DC-DC power loss	σ_{DC}	8 %
	Main supply loss	σ_{MS}	10%
	Cooling	σ_{Cool}	No needed (small cell)
	eNB antenna height	h_{TX_BS1}	7 m
	Tx antenna gain	G_1	7 dB
	Number of antennas	N_{Ant}	16, 32, 64
	Noise figure	N_f	9 dB
	UE antenna height	h_{UE}	1.5 m
Propagation losses	Morphology		
	Propagation model	$P_{L\_mod\_SUI}$	Modified SUI-NLOS
	Slope correction factor	α_{NLOS}	0.71
	AWGN	N_o	6 dB
	Shadow fading margin	X_{σ}	6 dB
	Exponent path loss	α	3.2

6.   RESULTS AND DISCUSSION

The received power level is commonly used in wireless communication as a measure of the quality of wireless connections because each radio receiver can only detect and decode signals with strengths greater than the minimum receiver sensitivity power. This section first discusses the effects of the path loss, fading and shadowing on the received power level at the UE within $cell_1$, as well as the interference effects from adjacent cells ($cell_2$ and $cell_3$) on the received power level at the UE over different cell radii. Because the EE is a function of both the data rate and the total BS power consumption, the second part of the discussion focuses on the data rate that will be delivered to the UEs under the effects of propagation path loss, multi-path (small-scale) fading, shadow (large-scale) fading and the interference power of the adjacent cells. The final part of this section evaluates the EE based on the proposed multi-LTE macro BSs system model. The received signal power decreases rapidly as the transmit-receive distance (radius of cell) increases ($P_{rx}(r) = P_{rx} r^{-\alpha}$. This power decrease is because the path loss, fading and shadowing within the cell, as well as the interference of adjacent cells and noise, are increasing. Figure 2 shows the effect of both the path loss, fading and shadowing within $cell_1$ and of the interference of adjacent cells ($cell_2$ and $cell_3$) on the received power level at the UE versus cell radii.

It is clear that when the radius increases, the received power level of BS_1 decreases and the interference power of BS_2 and BS_3 increases, reaching a maximum at the edge of $cell_1$. This can be expressed as the SINR given in (5) and defined as the ratio between the received power level of BS_1 and the interference power of BS_2 and BS_3 plus noise. Figure 3 shows the *SINR* over different radii. Where that the mm-wave spectrum (28 GHz) is very sensitive to the losses, SINR at edge of cell1 drops to -10.6 dB.
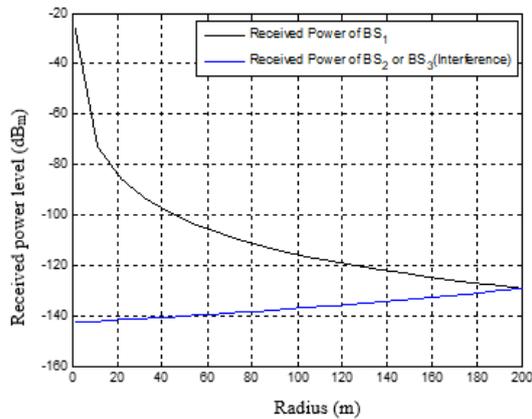

Figure 2. Cell radii versus received power level at $P_{tx\_BS1} = P_{tx\_BS2} = P_{tx\_BS3} = 32.04 \ dB_m$
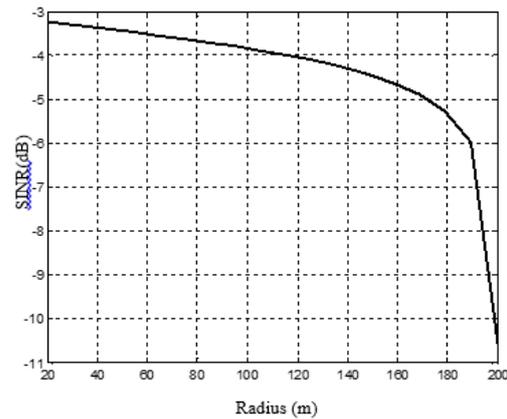
Figure 3. Cell radii versus SINR

As shown in (4), the data rate is directly proportional with the antennas and bandwidth, and logarithmically proportional with SINR. Hence, the key 5G considerations are focused on the physical layer (PHY), intensive deployment of 5G small cells with mm-waves along with large MIMO:
- 5G Small cells, radio coverage of 5G small cell BSs is 200 m. However, a simulation of network parameters for different cell radii is performed. As shown in Figure 3, when the distance between the BS and UEs has increased, SINR is degraded, which considered as the metric for quality of wireless connections. Thus, the worst received wireless signal of 5G small cell BS is -10.6dB at the edge of the cell1; which will reflect on the data rate as shown in (4) as well as on the amount of data transferred in the joule, as shown in (2); due to using a low order of modulation technique.
- Millimeter wave (mm-wave): a three BW values have investigated to cover the most potential standards, which are 0.25, 0.5, and 1 GHz. Based on (4), Figure 4 shows the relationship between the data rate and the SINR values for different bandwidths and for 64 transmit antennas.

The following analysis discusses the data rate at the edge of $cell_1$ over different of the BW values. As shown in Figure 5, the data rate up to 1.93, 3.86, and 7.72 Gbps with BW 0.25, 0.5, and 1 GHz, respectively. Which obtained based on (4). It is clear that at the largest BW the data rate amounted four times at the lowest BW. These results mean that the 5G small cell can support a new high-speed data application, including multimedia communications, online gaming, and high-quality video streaming. Anyway, since that the EE is a function of the data rate and BS power consumption. The EE performance versus the SINR for different BWs is shown in Figure 5, based on the multi-5G small cells network system proposed in Figure 3.

The total power consumption in this type of system grows proportionally with transmission power of the base station P_{tx_BS} as is shown in (3). As shown in Figure 5, the EE achieved at a 0.25 GHz BW and 64 antennas at the edge of the cell$_1$, where the SINR is -10.6 dB, can be up to 5.18 Mbits /J. This result computed using (2), a data rate of 1.93 Gbps taken from Figure 4, and by dividing by the total power consumption of 372.86 W (according to as shown in (3) $64\times$ [(4.12+0.7) / (1-0.08) (1-0.1)]). However, with a 1 GHz BW and 64 antennas, the EE can be as high as 20.70 Mbits/J, resulting in data rates of up to 7.72 Gbps, as shown in Figure 5.
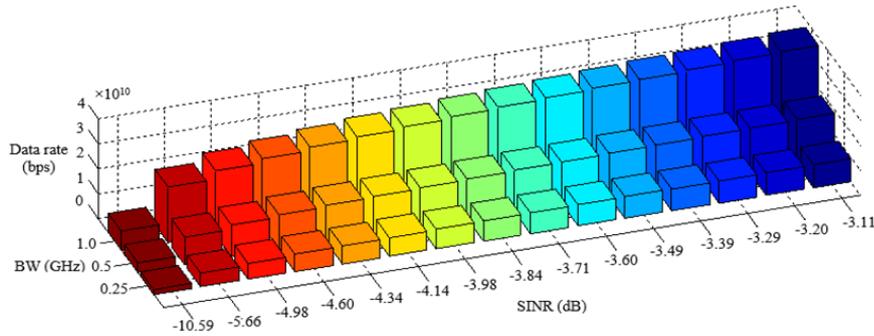

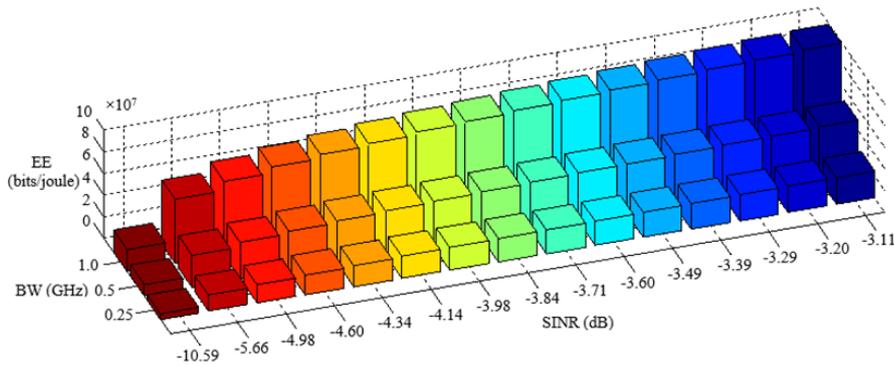Figure 4. Data rate versus different SINR values for different BWs at P_{tx_BS1}=32.04 dB$_m$ and N_{Ant}= 64

Figure 5. Energy efficiency versus different SINR values for different
BWs at P_{tx_BS1}= P_{tx_BS2} = P_{tx_BS3} = 32.04 dB$_m$ and N_{Ant}=64

- Large MIMO, is another method that can increase the capacity and EE [21-23]. Using Large MIMO technology, providing high multiplexing as well as array gain at the same time. Large MIMO technology is not only spectrum efficient but energy efficient as well. As the number of BS antennas increases, the received SINR increases linearly [24-26]. Figure 6 summarizes the data rate that can be achieved with various numbers of antennas for different BWs at the edge of cell$_1$.

At the edge of cell$_1$ (radius tual 200 m) where the SINR is the lowest (-10.6 dB), the total data rate with a 0.25 GHz BW and 32 antennas can be up to 0.96 Gbps. With a 1 GHz BW the total data rate can be up to 3.86 Gbps with the same number of antennas. However, the multiple signal paths due to multiple antennas at the transmitter are responsible for the large throughput. It is clear that when using 64 antennas, the data rate (1.93 Gbps with 0.25 GHz BW, and 7.72 Gbps with 1 GHz BW, respectively) is 2 times greater compared with using 32 antennas.

The data rate increases with an increasing number of antennas, and the EE is a function of the data rate (as shown by (2)). Therefore, the EE improves with a larger BW size and a larger number of antennas. Figure 7 shows EE versus the number of antennas for different BWs at the edge of cell$_1$. At the edge of cell$_1$ where the SINR is the lowest (-10.6 dB), the total EE with a 0.25 GHz BW and 16 antennas can be up to 1.29 Mb\j. With a 1 GHz BW the total EE can be up to 5.17 Mb\j with the same number of antennas. While, with 32 antennas the total EE with a 0.25 GHz BW can be up to 2.59 Mb\j, and with a 1 GHz BW the can be up to 10.35 Mb\j. Moreover, the EE values increased 4 times with a 64 antennas compare with 16 antennas, which amounted 5.17 Mb\j with a 0.25 GHz BW and 20.70 Mb\j with a 1 GHz BW.
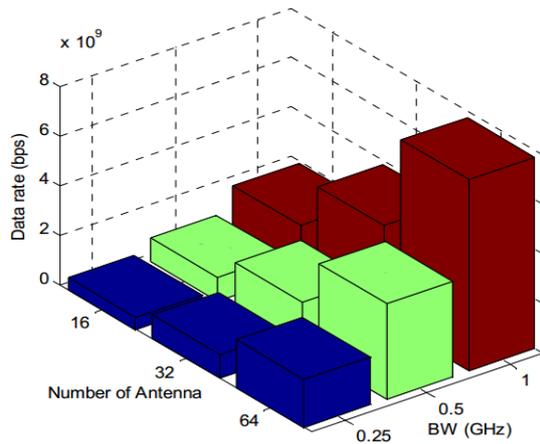
Figure 6. Data rate versus different BWs values for different number of antennas at P_{tx_BS1}= 32.04 dB$_m$ and the lowest SINR (at edge of cell$_1$)
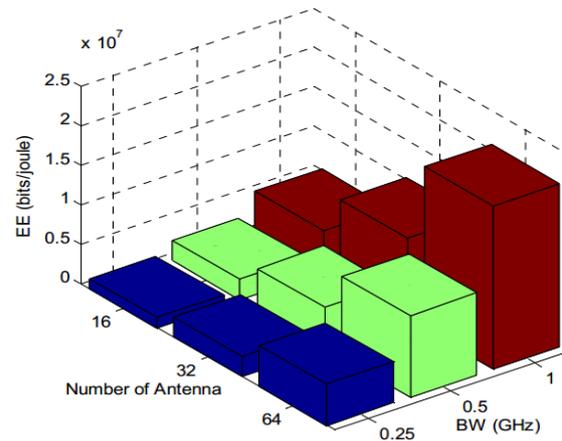
Figure 7. Energy efficiency versus different BW values for different number of antennas at P_{tx_BS1}= P_{tx_BS2} = P_{tx_BS3} = 32.04 dB$_m$ and at the lowest SINR (at edge of cell$_1$)

7. CONCLUSION

This paper presented a model and an investigation of the EE of multi-5G small cell system cellular networks. In addition, the concepts of new technologies of the large MIMO in the millimeter range communication, are considered. Since that the EE is a function of both the data rate and the total BS power consumption. Therefore, the EE improves with a larger BW size, a larger number of antennas, and decrease the total BS power consumption. The simulation results show that the large BW and the number of antennas combined with a high SINR increases the throughput, which increases the number of bits transferred per joule of energy and thus improves the EE of the cellular network.

REFERENCES

[1]   Niklas Heuveldop, "Ericsson Mobility Report," *Ericsson*, 2017, [accessed 27 January 2018], [Online], Available: https://www.ericsson.com/assets/local/mobility-report/documents/2017/ericsson-mobility-report-june-2017.pdf.
[2]   M.H. Alsharif and R. Nordin, "Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells," *Telecommunication Systems*, vol. 64, pp. 617-637, 2017.
[3]   A. Abrol and R.K. Jha, "Power Optimization in 5G Networks: A Step Towards GrEEn Communication," in *IEEE Access*, vol. 4, pp. 1355-1374, 2016.
[4]   A. Gupta and R.K. Jha, "A survey of 5g network: Architecture and emerging technologies," in *IEEE Access*, vol. 3, pp. 1206-1232, 2015.
[5]   Pimmy Gandotra, Rakesh Jha, and Sanjeev Jain, "Green Communication in Next Generation Cellular Networks: A Survey," in *IEEE Access*, vol. 5, pp. 11727-11758, 2017.
[6]   A.H. Jafari, D. López-Pérez, H. Song, H. Claussen, L. Ho, and J. Zhang, "Small cell backhaul: challenges and prospective solutions," *EURASIP Journal on Wireless Communications and Networking*, vol. 2015, no. 206, pp. 1-18, Aug. 2015.
[7]   F. Han, S. Zhao, L. Zhang, and J. Wu, "Survey of strategies for switching off base stations in heterogeneous networks for greener 5G systems," in *IEEE Access*, vol. 4, pp. 4959-4973, 2016.
[8]   A.I. Sulyman, A. Nassar, M.K. Samimi, G. Maccartney, T.S. Rappaport, and A. Alsanie, "Radio propagation path loss models for 5G cellular networks in the 28 GHZ and 38 GHZ millimeter-wave bands," in *IEEE Communications Magazine*, vol. 52, no. 9, pp. 78-86, Sep. 2014.
[9]   I. Chih-Lin, C. Rowell, S. Han, Z. Xu, G. Li, and Z. Pan, "Toward green and soft: a 5G perspective," in *IEEE Communications Magazine*, vol. 52, no. 2, pp. 66-73, Feb. 2014.
[10]   T. Chen, Y. Yang, H. Zhang, H. Kim, and K. Horneman, "Network energy saving technologies for green wireless access networks," in *IEEE Wireless Communications*, vol. 18, no. 5, pp. 30-38, Oct. 2011.
[11]   H.Q. Ngo, E.G. Larsson, and T.L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," in *IEEE Transactions on Communications*, vol. 61, no. 4, pp. 1436-1449, Apr. 2013.
[12]   P.S. Parihar, R. Saraswat, and S. Maheshwari, "Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems," *International Journal of Computer Applications*, vol. 111, no. 5, Feb. 2015.
[13]   L. Zhao, K. Zheng, H. Long, H. Zhao, and W. Wang, "Performance analysis for downlink massive multiple-input multiple-output system with channel state information delay under maximum ratio transmission precoding," in *IET Communications*, vol. 8, no. 3, pp. 390-398, Feb. 2014.

[14] X. Ge, C. Cao, M. Jo, M. Chen, J. Hu, and I. Humar, "Energy Efficiency Modelling and Analyzing Based on Multi-cell and Multi-antenna Cellular Networks," in *KSII Transactions on Internet and Information Systems*, vol. 4, no. 4, pp. 560-574, August 2010.

[15] A.A. Abdulkafi, T.S. Kiong, J. Koh, D. Chieng, A. Ting, and A.M. Ghaleb, "Energy efficiency of LTE macro base station," *2012 International Symposium on Telecommunication Technologies*, Kuala Lumpur, pp. 259-264, 2012.

[16] G. Auer, V. Giannini, C. Desset, I. Godor, P. Skillermark, M. Olsson, *et al.*, "How much energy is needed to run a wireless network?," in *IEEE Wireless Communications*, vol. 18, no. 5, pp. 40-49, Oct. 2011.

[17] W. Debus and L. Axonn, "RF Path Loss & Transmission Distance Calculations," *Axonn, LLC, Technical memorandukm*, Aug. 2006.

[18] X. Ge, H. Cheng, M. Guizani, and T. Han, "5G wireless backhaul networks: challenges and research advances," in *IEEE Network*, vol. 28, no. 6, pp. 6-11, Nov.-Dec. 2014.

[19] C.R. Anderson and T.S. Rappaport, "In-building wideband partition loss measurements at 2.5 and 60 GHz," in *IEEE Transactions on Wireless Communications*, vol. 3, no. 3, pp. 922-928, May 2004.

[20] A.V. Alejos, M.G. Sánchez, and I. Cuiñas, "Measurement and analysis of propagation mechanisms at 40 GHz: Viability of site shielding forced by obstacles," in *IEEE Transactions on Vehicular Technology*, vol. 57, no. 6, pp. 3369-3380, Nov. 2008.

[21] O. Edfors and F. Tufvesson, "Massive MIMO for next generation wireless systems," in *IEEE Communications Magazine*, vol. 52, no. 2, pp. 186-195, Feb. 2014.

[22] M.H. Alsharif, R. Nordin, N.F. Abdullah, and A.H. Kelechi, "How to make key 5G wireless technologies environmental friendly: A review," *Transactions on Emerging Telecommunications Technologies*, vol. 29, pp. e3254, 2018.

[23] M.H. Alsharif, R. Nordin, M.M. Shakir, and A.M. Ramly, "Small Cells Integration with the Macro-Cell Under LTE Cellular Networks and Potential Extension for 5G," *Journal of Electrical Engineering & Technology*, vol. 14, pp. 2455–2465, 2019.

[24] M.H. Alsharif, A.H. Kelechi, J. Kim, and J.H. Kim, "Energy Efficiency and Coverage Trade-Off in 5G for Eco-Friendly and Sustainable Cellular Networks," *Symmetry*, vol. 11, pp. 408, 2019.

[25] I. Khan, M.H. Alsharif, M.H. Zafar, M.O. Alassafi, M. Ashraf, Y. Huang, J. Kim, and J.H. Kim, "An Efficient Algorithm for mmWave MIMO Systems," *Symmetry*, vol. 11, pp. 786, 2019.

[26] S.L. Mohammed, M.H. Alsharif, S.K. Gharghan, I. Khan, and M. Albreem, "Robust Hybrid Beamforming Scheme for Millimeter-Wave Massive-MIMO 5G Wireless Networks," *Symmetry*, vol. 11, pp. 1424, 2019.

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