Tikrit Journal of Engineering Sciences (2023) 30 (3): 1-8
DOI: http://doi.org/10.25130/tjes.30.3.1

IRAQI Academic Scientific Journals

College of Engineering

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Energy-Efficient Massive MIMO Network

Israa Hilme Ahmed [a*], *Ayad Atiyah Abdulkafi* [b]

a Electrical Department, College of Engineering, Tikrit University, Iraq
b Electrical Department, College of Engineering- Shirqat, Tikrit University, Iraq

Keywords:
Energy Efficiency (EE), Next Generation MIMO, Power Consumption (PC), Spectral Efficiency (SE).

ARTICLE INFO

Article history:

Received:	01 Apr. 2023
Received in revised form:	01 July 2023
Accepted:	03 July 2023
Final Proofreading:	23 July 2023
Available online:	02 Aug.2023

Citation: Ahmed IH, Abdulkafi AA. Energy-Efficient Massive MIMO Network. Tikrit Journal of Engineering Sciences 2023; **30**(3): 1-8.
http://doi.org/10.25130/tjes.30.3.1

****Corresponding author:***

Israa Hilme Ahmed

Electrical Department, Engineering College, Tikrit University, Iraq

Abstract: Massive Multiple-Input Multiple-Output (Massive MIMO) is widely regarded as a highly promising technology for the forthcoming generation of wireless systems. The massive MIMO implementation involves the integration of a substantial number of antenna elements into base stations (BSs) to enhance spectral efficiency (SE) and energy efficiency (EE). The energy efficiency (EE) of base stations (BSs) has become an increasingly important issue for telecommunications network operators due to the need to take care of profitability while simultaneously minimizing their detrimental effects on the environment and addressing economic challenges faced by wireless communication operators. In this paper, the EE of massive MIMO networks and the relationship between EE, SE, and other parameters like bandwidth (B), number of antennas (M), circuit power, and number of users' equipment (K) are discussed and investigated. For a fixed circuit power (P_{FIX}), simulation results showed that the EE could be increased by about 1.12 as the number of antennas was doubled. The findings in this work also indicated an almost linear relationship between maximum EE and optimal SE, with a massive increase in the number of antennas when the power consumed by each antenna (P_{BS}) was included in circuit power. In addition, when considering the power consumed per user's equipment (P_{UE}) impact, the SE increased with the ratio (M/K), in which SE showed a cubic relationship against M/K. On the other hand, the EE increased with M/K ratio until M/K reached a specific value. The maximum EE (and hence optimum SE) was achieved by massive MIMO, where the number of antennas was three times the number of users. However, EE started degrading after this value, as the number of antennas was considered larger than the users' and consumed more energy, resulting in EE degradation.

كفاءة الطاقة لشبكة ضخمة متعددة المداخل والمخارج

إسراء حلمي أحمد [1]، و أياد عطية عبد الكافي [2]
[1] قسم الهندسة الكهربائية / كلية الهندسة / جامعة تكريت / تكريت - العراق.
[2] قسم الهندسة الكهربائية / كلية الهندسة - الشرقاط / جامعة تكريت / تكريت - العراق.

الخلاصة

تُعَدّ تقنية MIMOالضخمة تقنية واعدة لأنظمة الاتصالات اللاسلكية للجيل القادم. حيث يتم تجهيز محطات القاعدة في تقنية MIMO الضخمة بعدد كبير جدًا من عناصر الهوائي لتحسين الكفاءة الطيفية والطاقة. وفي الوقت نفسه، تعتبر كفاءة الطاقة لمحطات القاعدة مشكلة متزايدة بالنسبة لمشغلي الاتصالات للحفاظ على الربحية وللحد من التأثير السلبي الشامل على البيئة والقضايا الاقتصادية لمشغلي الشبكات اللاسلكية. في هذا العمل، نحقق في كفاءة الطاقة لشبكات Massive MIMO. يتم مناقشة العلاقة بين كفاءة الطاقة والكفاءة الطيفية وغيرها من المعاملات مثل النطاق الترددي(B) وعدد الهوائيات(M) وقدرة الدائرة ومعدات المستخدمين(K) في شبكة Massive MIMO.وتظهر نتائج المحاكاة أن كفاءة الطاقة يمكن زيادتها بمقدار 1.12 عندما يتم زيادة عدد الهوائيات بمقدار الضعف وعند استخدام قدرة الدائرة الثابتة. تشير نتائج هذا البحث إلى وجود علاقة تقريباً خطية بين كفاءة الطاقة القصوى والكفاءة الطيفية الأمثل مع زيادة كبيرة في عدد الهوائيات عندما يتم احتساب الطاقة المستهلكة من قبل كل هوائي في الطاقة الكلية للدائرة. وبالإضافة إلى ذلك، يزداد الكفاءة الطيفية بزيادة نسبة (M/K) حيث تظهر الكفاءة الطيفية علاقة مكعبية ضدM/K . ومن ناحية أخرى، يزداد كفاءة الطاقة مع زيادة نسبة M/K حتى تصل M/K إلى قيمة معينة. في الواقع، يتم تحقيق كفاءة الطاقة القصوى (وبالتالي الكفاءة الطيفية الأمثل) من خلال Massive MIMO عندما يصبح عدد الهوائيات ثلاثة أضعاف عدد المستخدمين. ومع ذلك، تبدأ كفاءة الطاقة في التدهور بعد هذه القيمة حيث يتم اعتبار عدد الهوائيات كبيرًا مقارنة بعدد المستخدمين وبالتالي يستهلكون المزيد من الطاقة مما يؤدي إلى تدهور كفاءة الطاقة.

الكلمات الدالة: كفاءة الطاقة - الجيل القادم ل MIMO -استهلاك الطاقة - الكفاءة الطيفية.

1.INTRODUCTION

It is common knowledge that the need for wireless communication has emerged as the most crucial factor that must be considered in designing any present wireless network. The traffic volume on NextG networks is anticipated to reach tens of exabytes per month. Because of this, the data rate that NextG networks will give will need to be 1000 times larger than what is currently offered by cellular systems [1]. Many techniques, such as the massive MIMO scheme implementation, the antenna beam forming improvement, the mm-Wave technology utilization, and the micro-cells and pico-cells implementation, are all potential methods to accomplish this goal [2-5]. To enhance the performance of the NextG network, all of these techniques are put into practice. Despite this, there is a trade-off to be made between the spectral and energy efficiencies to increase the network data rate [6]. Energy efficiency has become an increasingly important topic in recent years for numerous reasons, including economic, operating, and environmental concerns. Base stations (BS) are responsible for using an important portion of the total power required for an overall telecommunication network, often between 60% and 80 %. Because of this, telecom companies face significant operational costs due to their reliance on power supplies [7, 8]. In Ref [9], the authors found that the carbon footprint of worldwide information and communications technology in 2015 was 730 million metric tons of CO_2 equivalents, which accounted for 1.4% of world greenhouse gas emissions. In contrast, its operational energy consumption was 805 trillion Watt-hours, accounting for 3.6% of global power usage. These data demonstrate a constant drop in carbon footprint and power usage per subscription and GB, despite showing a slight rise compared to projections in 2010 [10]. In Ref [9], Malmodin and Lunden forecasted that the carbon footprint of ICT would decrease between 2015 and 2020 after having anticipated that the carbon footprint of information and communications technology would reach 1100 million metric tons of CO_2 equivalents by 2020 (1.9% of world greenhouse gas emissions) [10]. The Global e-Sustainability Initiative (GeSI) has generated marginally elevated approximations. According to a 2012 estimation, the carbon footprint of global ICT recorded 0.9 $GtCO_2e$ in 2011, which accounted for 1.9% of world greenhouse gas emissions. It was further predicted that by 2020, the carbon footprint of global ICT would increase to 1.27 $GtCO_2e$, representing 2.3% of the world's greenhouse gas emissions [11]. According to subsequent analysis, the projected carbon footprint of ICT in 2030 is anticipated to decrease to 1.25 $GtCO_2e$, representing 1.97% of the total global emissions [12]. In Ref [13], the authors estimated a higher level of electrical power use and the carbon footprint of global ICT. According to their mid-case scenario, it was predicted that in 2010, the global consumption of ICT amounted to 2037 TWh, which accounted for 11% of the total global electricity usage, and resulted in the emission of 1.3 $GtCO_2e$. The forecast indicated that this consumption and emission would increase to 2878 TWh (11% of the global electricity use) and 1.7 $GtCO_2e$ in 2020, and further to 8265 TWh (21% of the global electricity use) and 4.8 $GtCO_2e$ by 2030. Utilizing renewable energy as a power source is one of the strategies that may be used to lower CO_2 emissions and reduce fuel consumption, as demonstrated in [14-19]. Adapting these energy sources in communication system networks will be a promising approach that can help network operators to reduce the carbon footprints of mobile data communications and attain all their energy requirements through renewable energy sources. In this paper, a comprehensive model for investigating the EE of massive MIMO networks is introduced, and the relationship between EE, SE, and other parameters, such as bandwidth (B), number of antennas (M), circuit power, and number of users' equipment (K) in massive MIMO networks is discussed.

2. SYSTEM MODEL

2.1. Energy Efficiency

Energy efficiency (EE) within a wireless communication system pertains to the amount of accurately transmitted bits with the amount of power consumed. As per the definition above, EE is denoted as

$$EE = \frac{R}{PC} \qquad (1)$$

The energy efficiency unit is bit/Joule. The definition of energy efficiency in a cellular network is also referred to as the benefit-cost ratio, as it compares the data rate (R) in [bit/s] and power consumption (PC) in [W]. This ratio calculates the quality of service (data rate) concerning the associated costs (power consumption) [20].

2.2. Data Rates

In practical situations, achieving the maximum theoretical peak data rates is challenging due to the various channel impairments present, such as noise and interference from owned and other cells. These limitations make it hard to attain the peak data rate. However, the maximum theoretical data rate for a single antenna transmission in a static channel can be calculated using Shannon's formula, Eq. (2). The data rate (R) in bits per second can be represented in terms of two parameters, the bandwidth and the signal-to-noise ratio (SNR).

$$R = B\, log_2\,(1 + SNR) \qquad (2)$$

Boosting the signal-to-noise ratio (SNR) through higher transmission power enhances the spectral efficiency (SE); however, this improvement will soon reach a point where the network becomes limited by interference and cannot achieve high SEs. The data quantity that can be sent across a certain channel is referred to as its spectral efficiency, and it is measured in bits per second per Hertz (bit/s/Hz). As specified by Claude Shannon in his original work, the data rate is the factor that decides the maximum SE [21], as SE=R/B. In Ref [22, 23], the authors used different algorithms to improve the data rates.

2.3. Power Consumption

The power consumption (PC) must be calculated using the effective transmit power (ETP) rather than the radiated transmit power, and also considering the circuit power (CP) that is necessary for operating the cellular network equipment [20].

$$PC = ETP + CP \qquad (3)$$

$$ETP = \frac{1}{\mu} p \qquad (4)$$

p is transmitting power in [W], Power amplifier efficiency ($0 < \mu \leq 1$). The power amplifiers (PAs) are crucial elements in mobile base stations. Over the past decade, the energy efficiency of PAs used in 3G/4G mobile base stations significantly increased, reaching over 50%, due to the implementation of advanced techniques, such as Doherty, envelope tracking, out phasing, and the GaN devices and digital predistortion use [24]. Circuit power (CP) is a crucial component required to measure PC accurately and avoid misconceptions about EE. There are several scenarios for calculating the PC explained in the following sub-sections.

2.3.1. Fixed Power

The term "fixed power" (P_{FIX}) refers to a consistent quantity that incorporates both the energy used for control signals and the energy used by baseband processors and backhaul equipment for their load-independent operations.

$$CP = P_{FIX} \qquad (5)$$

The spectral efficiency becomes;

$$SE = lo\, g_2 (1 + (M-1) SNR) = lo\, g_2 \left(1 + (M-1) \frac{p}{\sigma^2} \beta \right) \qquad (6)$$

where σ^2 is the noise power, M is the number of antennas, and β represents the overall channel gain of the UE, and the EE becomes;

$$EE = \frac{B\; log_2 \left(1 + \frac{(M-1)p}{\sigma^2} \beta \right)}{\frac{1}{\mu} p + P_{FIX}} \qquad (7)$$

with A is the noise power to the average channel gain ratio.

$$A = \frac{\sigma^2}{\beta} \qquad (8)$$

Inserting Eq. (8) into Eq. (7) yields

$$EE = \frac{B \log_2 \left(1 + \frac{(M-1)p}{A}\right)}{\frac{1}{\mu} p + P_{FIX}} \qquad (9)$$

2.3.2. BS Antenna Power Consumption

When the number of antennas (M) in a base station increases, the number of RF chains connecting each antenna also increases. This means that increasing M results in an equal increase in the number of RF chains in the base station, which includes components such as power amplifiers (PAs), digital-to-analog converters (DACs), mixers, in-phase or quadrature-phase filters (I/Q), local oscillators (LOs), modulators, analog-to-digital converters (ADCs), and demodulators. All of these components consume energy. As a result, the circuit power (CP) of this type of performance will be nearly M times larger than the CP of a transceiver [20].

$$CP = P_{FIX} + MP_{BS} \qquad (10)$$

where P_{BS} refers to the amount of power used by the various circuit components essential to the functioning of each BS antenna. Then EE becomes

$$EE = \frac{B\log_2\left(1+\frac{(M-1)p}{A}\right)}{\frac{1}{\mu}p + P_{FIX} + M\,P_{BS}} \qquad (11)$$

2.3.3 Power Consumption of Users' Equipment

One of the most effective ways to enhance the per-cell spectral efficiency is using space-division multiple access (SDMA) transmission to simultaneously increase the number of active user equipment (UEs). With hundreds of antennas, massive MIMO can spatially multiplex a unique UEs group on the same time-frequency resource, resulting in high spectral and energy efficiency [25].

$$CP = P_{FIX} + M\,P_{BS} + K\,P_{UE} \qquad (12)$$

where K is multiple UEs, and P_{UE} includes the power needed by each circuit component of each user's equipment with one antenna, such as the DAC, I/Q mixer, filter, and so on. The SE considering the UE is

$$SE = \log_2\left(1+\frac{M-1}{K-1+K\bar{\beta}+\frac{A}{p}}\right) \qquad (13)$$

where $\bar{\beta}$ is the inter-cell interference, and K is the number of user equipment. The corresponding EE is

$$EE = \frac{BK\log_2\left(1+\frac{M-1}{K-1+K\bar{\beta}+\frac{A}{p}}\right)}{\frac{1}{\mu}K\,p + P_{FIX} + MP_{BS} + KP_{UE}} \qquad (14)$$

3. Simulation procedure and results

This section examines the factors that affect energy efficiency (EE). The impact of these parameters on EE was examined for different scenarios and circuit power.

3.1. Simulation procedure

The system parameters and simulation techniques are detailed in this section. For study campaigns, three main scenarios for calculating PC. Initially, the methods and procedures are described in detail, and the relationship between these factors was analyzed and demonstrated using MATLAB R2020a for simulations. The simulation model proposed for evaluating EE is depicted in Fig. 1. First, the system parameters, such as B, M, P_{FIX}, K, P_{BS}, P_{UE}, and the power amplifier, are defined. Then, the transmitted power and channel gain are calculated. The data rate is then determined. The EE is obtained based on each specific scenario. Finally, the optimal SE and corresponding maximum EE are determined to evaluate the performance of the proposed system.

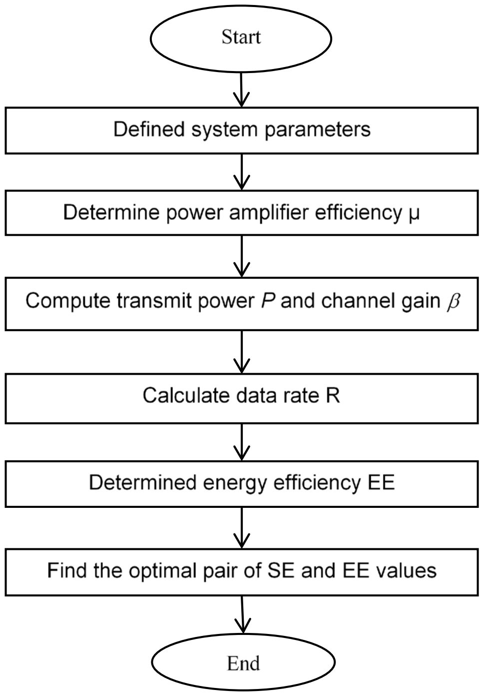

Fig.1 Flow Chart of The Proposed System Model.

3.2. Simulation results

This section presents the performed simulation results and discussion on the predefined model, divided into three subsections.

3.2.1. Impact of Fixed Power

When the circuit power (CP) includes only the fixed power (P_{FIX}), many parameters affect the EE performance.

3.2.2. Impact of Bandwidth

The bandwidth (B) significantly impacted a MIMO system's energy efficiency (EE). By increasing the B, the R of the system increased, leading to a higher EE, as shown in Fig. 2. The maximum EE was calculated for different simulated values of B ranging from 100 KHz to 1 GHz with a fixed spectral efficiency (SE) of 5.619 bits/s/Hz. The max EE improved with higher values of B, e.g., increasing B from 10 MHz to 20 MHz doubled the max EE, as shown in Table 1. which summarizes the results. However, wider bandwidth also requires more power, so there is a trade-off between bandwidth and EE in MIMO systems. The optimal EE was achieved by finding the right balance between the bandwidth and power consumption, including the operating variables for these sets.

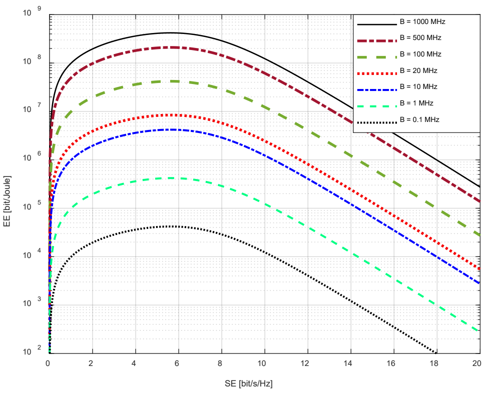

Fig. 2 Impact of B Allocation on EE.

Table 1. Max EE For Different B At Optimal SE=5.619 Bit/S/Hz

B[MHz]	Max EE[bit/Joule]
0.1	42.06×10^3
1	42.06×10^4
10	42.06×10^5
20	84.12×10^5
100	42.06×10^6
500	21.03×10^7
1000	42.06×10^7

Fig 2 demonstrates the variation between EE and SE for M=10, P_{FIX} =10W, A= −6 dBm, μ = 0.4, and B had been simulated ranged (100KHz-1GHz). First, the improvement can be seen in EE and SE with an increase of B in each of the different cases of B until the EE reached its maximum value at SE, i.e., equal to (5.619 bit/s/Hz). Then EE began to decline with an increase of SE because by increasing the spectral efficiency more than this amount, the transmitted power increased; consequently, the energy efficiency decreased. Second, the improvement can be seen in the maximum values of EE, with the increase of B to high values, with constant SE because it was unaffected by B. For example, when increasing B from 500MHz to 1000MHz, EE increased from 21.03×107 to 42.06×107 [bit/Joule] with constant SE at (5.619 bit/s/Hz), as shown in Table 1. Lastly, the trade-off between maximum EE and optimal SE with the range of B increased.

*3.2.3.*Impact of Transmitting Antenna

In massive MIMO systems, the transmitting antenna is critical in determining the system's overall performance. The number of antennas at the transmitter significantly impacts the system's ability to transmit a large amount of data simultaneously to multiple users, combat interference, and improve signal quality. Using a large number of transmitting antennas in massive MIMO can also improve the system's ability to achieve high spectral efficiency, which measures the amount of data transmitted per bandwidth unit. Additionally, a large number of transmitting antennas can improve the system's robustness to channel fading and shadowing, which can occur in wireless communications.

Overall, using a large number of transmitting antennas in massive MIMO can significantly improve the system's ability to support high data rates and provide improved coverage and reliability for users. The number of antennae (M) in the MIMO system significantly affected the energy efficiency. As M increased, EE increased with fixed SE, i.e., 8 bit/s/Hz, as shown in Fig. 3. Also, it can be noted that in the case of the massive increase in the number of antennas, a slight increase in the energy efficiency was obtained, which was higher.

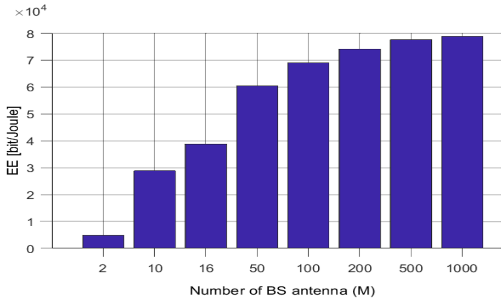

Fig. 3 The Impact of Transmitting Antenna on EE At SE=8 Bit/S/Hz

Fig 4. represents the effect of the number of the antenna (M) on EE and SE on BS for P_{FIX} = 10W, B=1MHz, A=−6dBm, μ=0.4, and M had simulated ranged (2-1000) antennas.

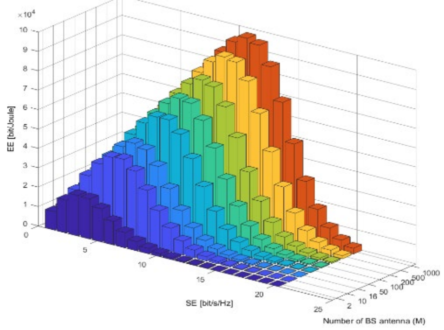

Fig. 4 Relationship Between SE and EE for Different Values Of M

The effect of increasing M appeared in EE after SE=4.5 bit/s/Hz because less SE can be achieved with fewer numbers of antennae, and then the EE became at its maximum value at optimal SE of each M. Then, EE decreased while SE increased because the transmitted power increased with increasing SE above the optimal value due to increasing M; consequently, the energy efficiency decreased. Also, it can be noted that when M was doubled, the max EE increased 1.12 times, as shown in Table 2. Furthermore, it can be noted that the trade-off between max EE and optimal SE improved with increasing M.

Table 2. Optimal (SE) at Max(EE) for Different Numbers of Antenna

Number of antenna (M)	Max EE[bit/Joule]	Optimal SE [bit/s/Hz]
2	21.25×10^4	3.434
10	42.06×10^4	5.619
16	47.56×10^4	6.179
50	60.94×10^4	7.529
100	69.22×10^4	8.36
200	77.62×10^4	9.202
500	88.91×10^4	10.33
1000	97.58×10^4	11.2

3.2.2.Impact of BS Antenna Power Consumption in CP

The relationship between EE and SE for a massive MIMO system is complex and is affected by M used in the system. The max EE-optimal SE trade-off curve is a function of M, characterized by a peak value at a certain point. As M increased, the max EE-optimal SE trade-off curve initially increased; however, it reached its maximum value and started to drop. This maximum value was achieved at M = 10, after which the trade-off curve started to drop. This opposes the findings in Fig. 4, demonstrating that the maximum EE-optimal SE trade-off graph usually grows with M. The reason for this behavior is the power consumption of the base station (P_{BS}), which increased with the number of antennae. The P_{BS} increased as the number of antennas increased, reducing the EE-optimal SE trade-off. This can be observed in Fig. 5. The relationship between EE and SE was almost linear for high numbers of antennas, i.e., 1000 antennae.

Fig 5 represents the relationship between SE and EE with the impact of BS antenna power consumption P_{BS}=1W, B=10 MHz, A= −6 dBm, μ = 0.4, P_{FIX}=10W, and M= 2, 10, 50, 100, 200,

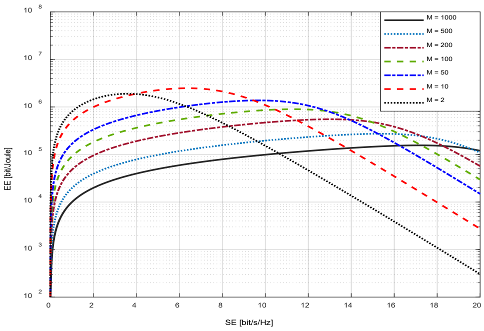

Fig. 5 Impact of BS Antenna Power Consumption (P_{BS}) In CP on The Relationship Between SE and EE

500, and 1000. As it can be seen, at first, with a tiny value of SE in each M, there were different values of EE before reaching its maximum value, which is in contrast to the results of Fig. 4. The effect of increasing M appeared in EE beyond SE=4.5 bit/s/Hz.Also, the improvement of max EE increased when M ≤10, and then max EE decreased as a linear function with massive M, Table 3.

Table 3. Optimal SE with Maximum EE at Different Ms with P_{BS}=1W

Number of antenna (M)	Max EE [bit/Joule]	Optimal SE [bit/s/Hz]
2	18.96×10^5	3.599
10	24.78×10^5	6.382
50	13.73×10^5	9.679
100	89.69×10^4	11.31
200	55.12×10^4	13.02
500	27.29×10^4	15.36
1000	15.57×10^4	17.17

3.2.3.Impact of Multiple Users' Equipment

The presence of multiple users' equipment in a MIMO system impacts its EE. In a multi-user MIMO system, multiple users share the same resources, such as bandwidth and power. The presence of more users increases the system's R and improves EE; however, it also increases interference and decreases signal quality, resulting in a reduction in EE. Adding more users also increased the system's power consumption, creating a trade-off between the number of users and EE in MIMO systems.

Fig 6 displays how Energy Efficiency (EE) varied with Spectral Efficiency (SE) for different M/K ratios. The conditions used were P_{FIX} = 10W, P_{BS} = 1W, P_{UE} = 0.5W, K = 10 users, $\bar{\beta}$ =-10dB, B = 100 kHz, μ = 0.5, and A= -6dBm.

The relationship between EE and SE was a single-peaked function based on the K. When (M/K) ≤ 3, EE improved as the number of K and M. However, EE dropped gradually when (M/K) > 3. The total SE increased with K; however, EE decreased with increasing the total SE because each UE used 0.5W of power, increasing the BS's power consumption. With the given values and simulations, Maximum EE was at M/K = 3, as shown in Table 4.

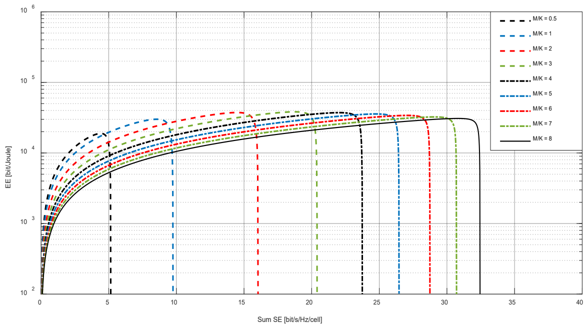

Fig. 6 EE as a Function of SE for Different M/K Ratios.

Table 4 Optimal SE with Maximum EE at Different M/K Ratios

M/K	Max EE[bit/Joule]	Optimal sum SE [bit/s/Hz]
0.5	18.88×10^3	4.411
1	30.04×10^3	8.555
2	37.37×10^3	14.48
3	38.23×10^3	18.72
4	37.23×10^3	22.04
5	35.67×10^3	24.75
6	33.99×10^3	27.06
7	32.36×10^3	29.05
8	30.83×10^3	30.81

4. CONCLUSIONS

This paper presents a framework for evaluating Energy Efficiency (EE) in massive MIMO wireless networks, which is seen as a way to reduce network power consumption and improve EE. Three circuit power scenarios (P_{FIX}, P_{BS}, and P_{UE}) were analyzed. Simulations showed that doubling the number of antennas increased EE by 1.12 with fixed circuit power (P_{FIX}). The study also found a nearly linear relationship between the maximum EE and optimal Spectral Efficiency (SE) as the number of antennas increased, including power consumption per antenna in circuit power (P_{BS}). SE increases with the ratio (M/K) and has a cubic relationship with M/K. EE improved until a certain M/K value was reached, with the maximum EE and optimal SE achieved when the number of antennas was three times the number of users considering the power consumed by each user (P_{UE}). However, EE decreased when the number of antennas became larger than the number of users, leading to higher energy consumption and degraded EE. The EE models used in this paper assumed a static power consumption scenario, i.e., the power consumption was independent of the load variation, which is left for future work.

Nomenclature

A	The ratio of the noise power to the average channel gain [dBm]
B	Bandwidth [MHz]
CP	Circuit power [W]
EE	Energy efficiency [bit/Joule]
ETP	The effective transmit power
K	Number of user's
M	Number of antenna
p	Transmitting power
P_{BS}	The power consumed of each BS antenna [W]
PC	Power consumption
P_{FIX}	Fixed power in [W]
PUS	The power consumed of each single-antenna user equipment (UE) [W]
R	Data rate [bit/s]
SE	Spectral efficiemcy [bit/s/Hz]
SNR	Signal to noise ratio
UE	User's equipment
σ^2	The noise power
$\bar{\beta}$	The relative strength of the inter-cell interference [dB]
μ	Power amplifier efficiency

REFERENCES

[1] Ye J, He Y, Ge X, Chen M. **Energy Efficiency Analysis of 5G Ultra-Dense Networks Based on Random Way Point Mobility Models**. 19th International Symposium on Wireless Personal Multimedia Communications (WPMC): IEEE; 2016. pp. 177-182.

[2] Boshkovska E, Ng DWK, Dai L, Schober R. **Power-Efficient and Secure Wpcns With Hardware Impairments and Non-Linear EH Circuit.** *IEEE Transactions on Communications* 2017;**66**(6):2642-2657.

[3] Shahab MM, Hardan SM, Hammoodi AS. **A New Transmission and Reception Algorithms for Improving the Performance of SISO/MIMO-OFDM Wireless Communication System.** *Tikrit Journal of Engineering Sciences* 2021;**28**(3):146-158.

[4] Nawaf SF. **Channel Capacity Improvement of MIMO Communication Systems Using Different Techniques.** *Tikrit Journal of Engineering Sciences* 2018;25(1):36-41.

[5] Larsson EG, Edfors O, Tufvesson F, Marzetta TL. **Massive MIMO for Next Generation Wireless Systems.** *IEEE communications magazine* 2014;**52**(2):186-195.

[6] Al-Heety, A. T., Islam, M. T., Rashid, A. H., Ali, H. N. A., Fadil, A. M., & Arabian, F. **Performance Evaluation of Wireless Data Traffic in Mm Wave Massive MIMO Communication.** *Indones J Electr Eng Comput* Sci 2020;**20**(3).

[7] Jahid A, Hossain S. **Dimensioning of Zero Grid Electricity Cellular Networking with Solar Powered Off-Grid BS**. 2017 2nd International Conference on Electrical & Electronic Engineering (ICEEE): IEEE; 2017. p. 1-4.

[8] Jahid A, Ahmad AS, Hossain MF. **Energy Efficient BS Cooperation in DPS Comp Based Cellular Networks with Hybrid Power Supply.** 2016 19th International Conference on Computer and Information Technology (ICCIT): IEEE; 2016. p. 93-98.

[9] Malmodin, J., & Lundén, D. (2018). **The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015.** *Sustainability*, **10**(9), 3027.

[10] Malmodin J, Bergmark P, Lundén D. **The Future Carbon Footprint of The ICT and E&M Sectors.** *On Information and Communication Technologies* 2013;12.

[11] Riva D. GeSI SMARTer 2020: **The Role of ICT in Driving a Sustainable Future.** 2012.

[12] Initiative Ge-S. SMARTer2030, **ICT Solutions for 21st Century Challenges. Executive Summary:** *ICT Solutions for 21st Century Challenges* 2015;8.

[13] Andrae AS, Edler T. **On Global Electricity Usage of Communication Technology:** trends to 2030. *Challenges* 2015;**6**(1):117-157.

[14] Mohammed BF. **Position Control of Solar Panel Receiver by Joint Generated Power and Received Signal Power Maximization.** *Tikrit Journal of Engineering Sciences* 2018;**25**(3):24-29.

[15] Alsharif MH. **Comparative Analysis of Solar-Powered Base Stations for Green Mobile Networks.** *Energies* 2017;**10**(8):1208.

[16] Lubritto, C., Petraglia, A., Vetromile, C., Curcuruto, S., Logorelli, M., Marsico, G., & D'Onofrio, A. **Energy and Environmental Aspects of Mobile Communication Systems.** *Energy* 2011;36(2):1109-1114.

[17] Hou J, Gao Y. **Greenhouse Wireless Sensor Network Monitoring System Design Based on Solar Energy**. 2010 International Conference on Challenges in Environmental Science and Computer Engineering: IEEE; 2010. p. 475-479.

[18] Yi G, Guiling S, Weixiang L, Yong P. **Wireless Sensor Node Design Based on Solar Energy Supply.** 2nd International Conference on Power Electronics and Intelligent Transportation System (PEITS): IEEE 2009. p. 203-207.

[19] Zedan MH, Khalaf HJ, Shaker AM. **Optimum Design of Parabolic Solar Collector with Exergy Analysis.** *Tikrit Journal of Engineering Sciences* 2017;**24**(4):49-57.

[20] Björnson E, Hoydis J, Sanguinetti L. **Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency.** *Foundations and Trends® in Signal Processing* 2017;**11**(3-4):154-655.

[21] Shannon CE. **A mathematical theory of communication**. *The Bell System Technical Journal* 1948;**27**(3):379-423.

[22] Hardan SM. **Improvement the Transmission Efficiency for Wireless Packet Communication Systems Using Automatic Control for Power and Time Slot Width of Slotted Non Persistent ISMA Protocol**. *Tikrit Journal of Engineering Science (TJES)* 2011;**18**(3):81-88.

[23] Assarut R, Husada MG, Yamamoto U, Onozato Y. **Data rate improvement with dynamic reassignment of spreading codes for DS-CDMA**. *Computer Communications* 2002;**25**(17):1575-1583.

[24] Kunihiro K, Hori S, Kaneko T. **High Efficiency Power Amplifiers for Mobile Base Stations: Recent Trends and Future Prospects for 5G**. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences* 2018;101(2):374-384.

[25] Zhang J, Wei Y, Björnson E, Han Y, Jin S. **Performance Analysis and Power Control of Cell-Free Massive MIMO Systems with Hardware Impairments**. *IEEE Access* 2018;6:55302-55314.