Computers, Materials & Continua
DOI:10.32604/cmc.2021.017711
Article

Tech Science Press

Adaptive Cell Zooming Strategy Toward Next-Generation Cellular Networks with Joint Transmission

Abu Jahid[1], Mohammed H. Alsharif[2], Raju Kannadasan[3], Mahmoud A. Albreem[4], Peerapong Uthansakul[5,*], Jamel Nebhen[6] and Ayman A. Aly[7]

[1]Department of Electrical and Computer Engineering, University of Ottawa, Ottawa, K1N 6N5, ON, Canada
[2]Department of Electrical Engineering, College of Electronics and Information Engineering, Sejong University, Seoul, 05006, Korea
[3]Department of Electrical and Electronics Engineering, Sri Venkateswara College of Engineering, Sriperumbudur, 602117, India
[4]Department of Electronics and Communications Engineering, A'Sharqiyah University, Ibra, 400, Oman
[5]School of Telecommunication Engineering, Suranaree University of Technology, Nakhon Ratchasima, Thailand
[6]Prince Sattam Bin Abdulaziz University, College of Computer Engineering and Sciences, Alkharj, 11942, Saudi Arabia
[7]Department of Mechanical Engineering, College of Engineering, Taif University, Taif, 21944, Saudi Arabia
[*]Corresponding Author: Peerapong Uthansakul. Email: uthansakul@sut.ac.th
Received: 08 February 2021; Accepted: 12 March 2021

Abstract: The Internet subscribers are expected to increase up to 69.7% (6 billion) from 45.3% and 25 billion Internet-of-things connections by 2025. Thus, the ubiquitous availability of data-hungry smart multimedia devices urges research attention to reduce the energy consumption in the fifth-generation cloud radio access network to meet the future traffic demand of high data rates. We propose a new cell zooming paradigm based on joint transmission (JT) coordinated multipoint to optimize user connection by controlling the cell coverage in the downlink communications with a hybrid power supply. The endeavoring cell zooming technique adjusts the coverage area in a given cluster based on five different JT schemes, which will help in reducing the overall power consumption with minimum inter-cell interference. We provide heuristic solutions to assess wireless network performances in terms of aggregate throughput, energy efficiency index (EEI), and energy consumption gain under a different scale of network settings. The suggested algorithm allows efficient allocation of resource block and increases energy and spectral efficiency over the conventional location-centric cell zooming mechanism. Extensive system-level simulations show that the proposed framework reduces energy consumption yielding up to 17.5% and increases EEI by 14%. Subsequently, a thorough comparison among different JT-based load shifting schemes is pledged for further validation of varying system bandwidths.

Keywords: Wireless networks; green communications; C-RAN; coordinated multipoint; energy efficiency

1 Introduction

With the technological advancement of cellular networks, by 2023, more than 70% of the population will have wireless connectivity globally, and fifth-generation (5G) connectivity will reach over 10%. The rapid growth of wireless subscribers and corresponding multimedia applications increases energy consumption and deteriorates the global warming phenomenon. Internet subscribers are expected to increase up to 69.7% (6 billion) from 45.3% and 25 billion Internet-of-things connections by 2025 [1]. To deal with the exponential growth of subscribers and smart devices, the telecom industries are extensively deploying more small base stations (BSs) and wireless equipment in radio access networks. The consequences of this upgrade significantly increase the network energy expenditures, which also elevated capital and operational expenses. However, cellular networks consume approximately 0.7% of the global power expenditure and 4%–5% of the information and communication technology (ICT) circle [2]. BSs in cloud radio access networks (C-RAN) are generally believed to be the main energy-hungry equipment in telecom networks, where energy consumption is directly related to the incoming traffic profile [3]. From the energy efficiency (EE) perspectives, wireless networks can be optimized by the following: (i) improving the hardware components, (ii) optimizing radio transmission process, (iii) turning off BS components, (iv) deployment of small cells, (v) curtailing energy losses, and (vi) adopting renewable energy (RE) sources [4]. This study focused on integrating the RE supply through the adaptive cell zooming policy under a green radio communication scheme.

A study reveals that the ICT sector is one of the key sources of global carbon emissions from fossil fuel combustion. Doubling the carbon production rates leads to a 6°C increase in the planet's temperature [5]. Moreover, the massive usage of fossil fuels constitutes a significant amount of energy production costs. Over the past few years, the application of RE has been prompted to provide an appealing power supply solution for BSs. Numerous studies focusing on green communications showed that a substantial reduction of operating costs and dependency on the conventional grid supply ensures minimum toxic gas emissions [6]. Considering the intermittent characteristics of RE availability, empowering the BSs with an energy supply from a standalone source cannot be guaranteed. The design of joint power supply technology including reliable grid energy and the cheap RE to power the BSs has become an emerging method for a large-scale cellular infrastructure [2]. One of the key design issues in exploiting maximum green energy utilization is to maximize EE by decreasing the grid energy purchase and CO_2 contents.

Recently, cellular networks have adopted the technique of multiple BS coordination in a cluster referred to as a coordinated multipoint (CoMP) transmission by utilizing the same frequency and time resources [7]. The CoMP technique is primarily introduced to mitigate the interference and spectrum scarcity problems by serving the same user equipment (UE). In CoMP transmission, BSs coordinate in such a way that either BSs serve to a single UE using the same network resources or BSs coordinate transmission among themselves to cancel out inter-cell interference. In addition, the CoMP technique has the potential to improve throughput performance by enhancing received signal quality and spectral efficiency (SE), thereby ensuring signal fairness [8]. Based on the data availability, the downlink CoMP can be classified into three categories, namely, dynamic point transmission, joint transmission (JT), and coordinated beamforming. This study focuses on different types of JT CoMP techniques into hybrid-powered 5G cellular networks by identifying better coordination strategies.

Typically, BSs are operating under maximum transmission power regardless of the traffic demand, which can incur additional power loss during low traffic hour periods. The BSs are anticipated to dynamically adjust, that is, shut-down/wake-up, according to the temporal variation of traffic load or other factors, such as UE-BS distance and availability of resource blocks (RBs) in the context of energy-efficient 5G cellular communications. Moreover, the cell zooming mechanism in BSs enables to dynamically adjust its coverage based on the traffic demand and increase the retrenchment of power expenditure under given criteria [9]. With grid-enabled macrocell BSs, the neighboring BSs cannot be forced to a full sleep mode for a long period of time as the inter-site distance between the BSs is identical in a cluster. A previous study [10] showed that a UE of poor channel conditions occupies considerable RBs to provide a given bit rate. This study considers the joint coordination CoMP technique where a UE receives the best signal quality owing to a higher number of RB allocation. As a result, the BS-centric cell zooming algorithm has been recognized as a more energy-efficient method of serving more numbers of UEs with a given RBs over the UE-centric way.

1.1 Related Works

Several previous studies paid attention to BS topology management considering traffic redistribution during off-peak hours. In [11], the authors reported the cell zooming method based on the traffic demand fluctuations without investigating the data transmission quality. Then, in [12], the authors suggested a suboptimal BS on/off method that is distributively implemented to save overall energy consumption. However, this study ignored the dynamic fluctuations of traffic load and received signal quality. In addition, the authors in [13] pointed out transmission quality issues, where the transmission power and cell coverage adaptions are based according to the traffic load, but [13] analyzed for a single-cell case. Furthermore, authors in [14] proposed energy procurement between cellular operators as a single group, where the BSs share the traffic arrivals by turning off the BS into a sleep mode during low traffic hours.

To reduce the carbon footprints more effectively, the issues of energy harvested-enabled green BSs have been developed to incorporate the cell zooming scheme [15]. By taking advantage of hybrid energy supplies, BSs are designed to overcome the limitations of standalone RE-powered cellular networks. To mitigate the RE fluctuations among collocated BSs, the authors in [16] proposed an energy cooperation policy between BSs according to the traffic profile. The authors examined the joint optimization of RB allocation and BS on/off [17] and optimal packet scheduling [18] with hybrid supplies under user blocking constraints. The tradeoff between EE and traffic latency is investigated in [19], where the burst traffic patterns exhibit better EE performance enabling more BSs into a sleeping mode compared with uniform traffic distributions. All of the reported research works analyzed the system performances through sleep–wake up or cell zooming mechanisms by adjusting traffic load and transmission power. However, none of these works have analyzed the CoMP-based cell zooming technique considering traffic load fluctuations.

Authors in [20] presented the concept of cell breathing in the form of cell zooming, traffic offloading, and BS turning off for heterogeneous networks (HetNets) for EE BS topology management. Then, the authors extended this work contemplating the multi-metric UE-BS association approach with hybrid supplies [21]. A joint radio resource management and load balancing technique are proposed for HetNets based on traffic density-differentiated policies [22]. The authors in [23] provided insights on a coordinated small cell on/off schemes, providing offloading support for macrocell BSs. The authors proposed a green user association policy for cloud RAN network architecture based on the virtualized algorithms to measure energy availability information [24]. The authors in [14] studied energy-aware adaptive transmit power control mechanisms for energy cooperation-aided mmWave renewable-powered cellular networks. This work does not consider the stochastic nature of traffic diversity and coordination mechanisms. In the present study, we examined the EE and SE performance defining some performance metrics accounting for adaptive cell zooming policy and dynamic nature of traffic load.

1.2 Contributions

Existing available research works focusing on improving transmission capacity, quality of experience, and SE ignoring the demand for energy-efficient aspects for mobile communications. To the best of the authors' knowledge, this study first considers the CoMP-based cell zooming technique in the context of green cellular communications. Notably, the system only considers two BSs for user-BS connection algorithms under JT CoMP-enabled cell-adjusting technique. The major contributions of this study can be outlined as follows.

- A generalized solar photovoltaic (PV)/grid aggregate power supply for the C-RAN is developed, which addresses EE and ecological issues.
- Several performance metrics, such as energy consumption gain (ECG), energy-saving index (ESI), and energy efficiency index (EEI), which are used to assess overall EE varying load factor and system bandwidth, have been illustrated.
- A heuristic energy-efficient framework is developed by integrating a joint coordination-based cell zooming scheme while considering the variation of RE production and traffic arrivals. Various user association schemes, such as SINR-SINR, SINR-traffic, SINR-distance, traffic-distance, and distance-distance, are exploited in the suggested framework, which has not been examined in the literature yet. After that, the system performance is compared with the existing non-CoMP-based cell zooming scheme for validation.

The rest of this paper is organized as follows. Section 2 presents the system model. Section 3 discusses performance analysis, which includes simulation setup and results. Finally, Section 4 concludes the study by highlighting the attained results.

2 System Model

2.1 Network Architecture

A large-scale two-tier homogeneous cellular network comprising of N number of BSs (B) and baseband unit (BBU) pool is considered where $\mathrm{B} = \{B_1, B_2, \ldots, B_N\}$ and covering an area $A = \{A_1 \cup A_2 \cup \ldots \cup A_N\} \subset \mathrm{R}^2$. Notably, A_i is the coverage area of BS B_i, $\forall i \in \{1, \ldots, N\}$. All the BSs are assumed to be arranged in a remote radio head (RRH)-enabled hexagonal pattern with a 2/2/2 tri-sector. Notably, the OFDMA technique cancels out the intra-cell interference, and all the orthogonal RBs are reused among the BSs. The transmission process can take place from the baseband unit (BBU) to the RRH unit through an optical fiber cable and RRHs to users' connection wirelessly. The BBU pool can decide on the data distribution-based coordination method. All the individual BS in the considered network is powered by an on-site solar energy harvester with an adequate battery bank and grid supply connectivity. A smart energy management unit prevents the storage device from overcharging/discharging and controls the key selection of primary energy sources. Notably, the grid electricity plays as the standby supply during the malfunctioning of green supply. Different JT CoMP-based cell zooming schemes are deployed to evaluate the best-received signal intensity to serve UEs, which is depicted in Fig. 1. The centralized control server (i.e., BBU pool) monitors the signal power, traffic demands, and UE-BS distances to perform zooming algorithms to maximize EE.

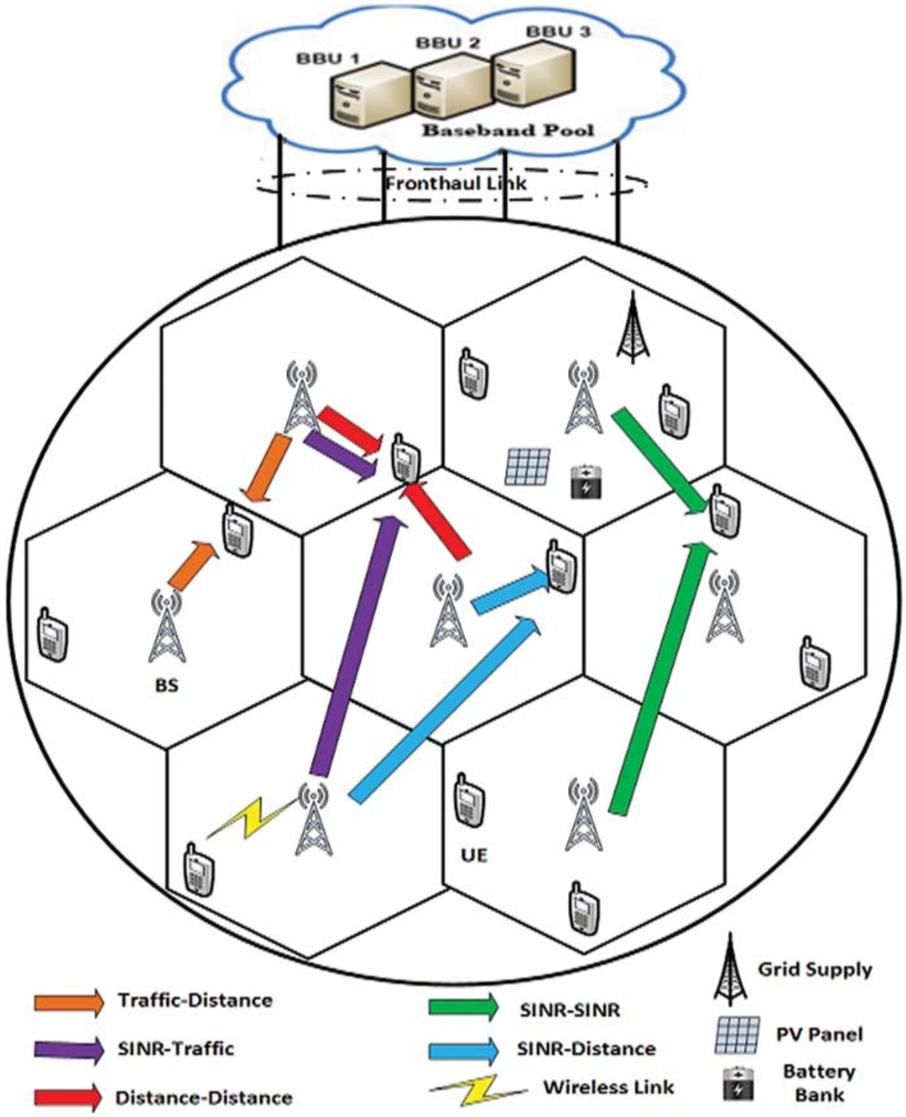

Figure 1: JT CoMP-based user association schemes

2.2 Wireless Link Model

We consider log-normally distributed shadow fading channel model, where path loss in dB can be expressed as

$$\gamma\,(d) = \gamma\,(d_o) + 10\alpha \log\left(\frac{d}{d_o}\right), \tag{1}$$

where d is the separation between the transmitter and receiver. $\gamma\,(d_0)$ is the free-space reference path loss in dB at a distance d_0, and α denotes the path-loss exponent.

The received signal power in dBm for kth UE at a distance $d = d^{i,k}$ from ith BS B_i under JT CoMP transmission is given by

$$P_R^{i,k} = P_{tx}^{1,k} + P_{tx}^{2,k} - \gamma\,(d) + X_\sigma, \tag{2}$$

where $P_T^{i,k}$ is the transmitted power in dBm and X_σ is the shadow fading parameter modeled as a zero-mean Gaussian random variable with a standard deviation σ dB. Considering that two coordinated BSs serve a single UE simultaneously in JT CoMP transmission, two different transmit powers are considered in the calculation. However, the inter-cell interference can be expressed as

$$I_{k,\,\mathrm{inter}} = P_{\mathrm{inter}}^{i,k} = \sum_{m \neq 1,2} P_{tx}^{m,k}. \tag{3}$$

Notably, that intra-cell interference is zero because of the orthogonal condition. P_N is the additive white Gaussian noise power given by $P_N = -174 + 10\log_{10}(BW)$ in dBm, where BW is the bandwidth in Hz. The SINR $\Psi_{i,k}$ at kth UE from BS B_i can be given by

$$\Psi_{i,k} = \frac{P_R^{i,k}}{I_{k,\,\mathrm{inter}} + \mathrm{P}_N}. \tag{4}$$

2.3 Solar PV Generation

The solar energy generated at BS $i \in \{1, \ldots, \mathrm{N}\}$ during time slot t is a random variable denoted by $r_i(t) \in [0, r_i^{max}]$, where r_i^{max} is the maximum available solar energy generation by B_i. However, the annual solar energy generation can be calculated by

$$E_{PV} = C_{PV} \times \Delta_r \times gamma \times \zeta \times 365\ days/year, \tag{5}$$

where C_{PV} the rated PV array capacity in kW, Δ_r is the average daily solar radiation intensity in $kWh/m^2/day$ (4.65 as shown in Fig. 2), *gamma* is the dual-axis tracking factor (typically 1.3), and ζ is the derating factor that considers the effects of dust, wire loss, and temperature fluctuations on the solar power production.

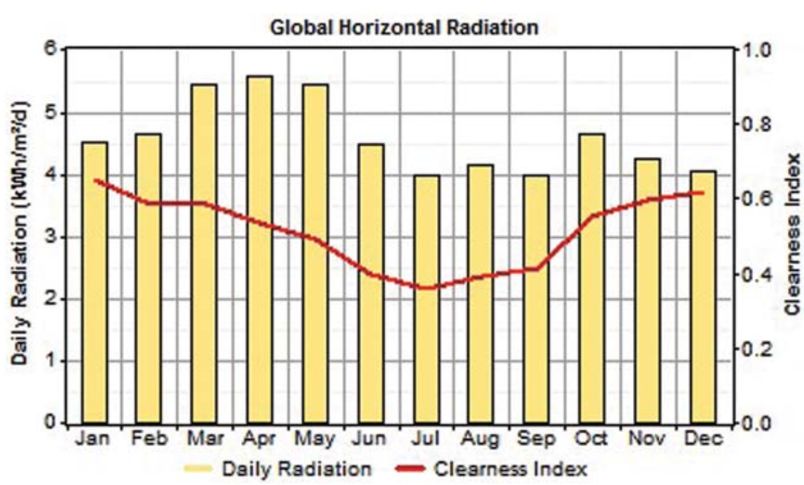

Figure 2: Cell solar radiation profile in Dhaka city

2.4 Macrocell Power Model

The total estimated power consumption by a macrocell BS is function of traffic intensity (χ) and number of transceivers (N_{TRX}) is given by [3]:

$$P_{in} = \begin{cases} N_{TRX}\left[P_1 + \Delta_p P_{TX}(x-1)\right], & if\ \ 0 < x < 1 \\ N_{TRX} P_{slp} & if\ \ x = 0 \end{cases}. \tag{6}$$

$P_1 = P_0 + \Delta_p P_{TX}$ is the the maximum power consumption of a BS sector, and P_0 is the consumption at the idle state. Tabs. 1 and 2 show the parameters of BS power consumption. However, P_1 can be computed as

$$P_1 = \frac{N_{TRX}\dfrac{B}{10\ \ MHz}\left(P'_{BB} + P'_{RF}\right) + \dfrac{P_{TX}}{\eta_{PA}\left(1-\sigma_{feed}\right)}}{\left(1-\sigma_{DC}\right)\left(1-\sigma_{cool}\right)}, \tag{7}$$

where P'_{BB} and P'_{RF} are the baseband and RF power consumption, respectively. B represents the system bandwidth, and η_{PA} defined the power amplifier efficiency. σ_{DC}, σ_{feed}, and σ_{cool} represent the loss incurred by DC power conversion, feeder cable, and active cooling, respectively.

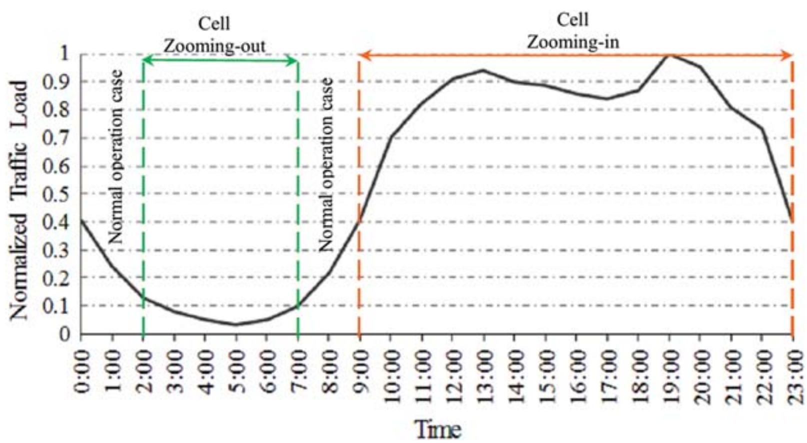

Figure 3: Daily traffic demand profile

Table 1: BS approximate power consumption model parameters [1]

BS type	N_{TRX}	P_{TX} $[W]$	P_0 $[W]$	Δ_p	P_{slp} $[W]$
Macro	6	20	84	2.8	56

Table 2: BS approximate power model parameters [1]

σ_{feed} [dB]	η_{PA} (%)	P'_{BB} [W]	P'_{RF} [W]	σ_{DC} (%)	σ_{cool} (%)	P_{PA}
0	31.1	29.6	12.9	7.5	0	64.4

2.5 Performance Metrics

Energy consumption gain (ECG): ECG metrics account for the energy required to send a request in data transmission over a particular duration. ECG in green communications can be defined as the ratio of the energy consumption ratio metrics of the proposed system to the reference schemes under the specified network settings [24]. For instance, the network architecture without cell zooming is considered a reference baseline, and the cell zooming-enabled green-powered cellular system is the proposed scheme recognized as a more energy-efficient architecture. In other words, ECG quantifies the improvement of energy consumption with respect to the reference baseline scheme. A system with lower ECG is identified as more energy-efficient as this system consumes lower power to transmit the same amount of data transmission.

$$ECR = \frac{ECR_{proposed}}{ECG_{ref}} \times 100\%. \tag{8}$$

Energy-saving index (ESI): ESI metrics measure the energy-saving gain introducing the cell zooming concept under different zoom-out ranges. ESI can be defined as

$$ESI = \frac{E_\rho - E_\mu}{E_\rho} \times 100\% \tag{9}$$

where E_ρ indicates the power consumption without incorporating the cell zooming technique and E_μ denotes the power requirement with cell zoom out for the entire cellular architecture respectively.

Load factor (δ): δ represents the ratio of the number of RBs occupied (RB_O) to the available RB (RB_T) in a given system bandwidth. Without loss of generality, we presume that one RB is occupied by a single active user, and the occupancy rate of the RB allocation is linearly proportional to the incoming traffic profile. As the number of demand request increases, the number of occupied RBs to satisfy the QoS also increases. For example, a cellular system operating at 10-MHz bandwidth has 50 RBs that can be allocated simultaneously at a particular time. Under the proposed framework, when the total available RBs are occupied in a particular BSs, the next available users can be associated with the neighboring BSs without a call service drop. However, δ can be expressed as

$$\delta = \frac{RB_o}{RB_T}. \tag{10}$$

Energy efficiency (η_{EE}): η_{EE} cab be defined as the ratio of total achievable throughput per grid power consumption.

$$T_{tot} = \sum_{k=1}^{U} \sum_{i=1}^{N} B \log_2 \left(1 + SINR_{i,k}\right), \tag{11}$$

$$\eta_{EE} = \frac{T_{tot}}{P_{grid}}, \tag{12}$$

where $P_{grid} = \sum_{i=1}^{N} P_{in}(i, t) - \sum_{i=1}^{N} P_G(i, t)$ is the net grid energy consumption in BS B_i at time t, $P_{in}(t)$ is the total power supply in BS B_i at time t, and $P_G(t)$ is the harvested RE at time t. Moreover, the EEI is an equipment level metric that quantifies the enhancement of EE performance and is considered by the proposed framework as the reference system. EEI can be defined as follows

$$\eta_{EE} = \frac{T_{tot}}{P_{in}}. \tag{13}$$

2.6 Cell Zooming Algorithm

The idea of cell zooming allowing new incoming users by adjusting the cell size depends on different user association mechanisms. The cell zooming technique has the potential to increase EE by turning off lightly loaded BSs in a cluster. The centralized control server in the BBU pool coordinates the traffic load and makes zooming decisions accordingly. The zooming server broadcasts zooming in when the traffic intensity is higher and vice versa. The provisioning of the proposed sleep mode mechanism governed by the cell zooming method substantially reduces additional energy dissipation over the conventional user-centric zooming technique. Fig. 4 depicts the cell zooming strategy. Moreover, for better understanding, Figs. 4 and 5 show the heuristic cell zooming algorithm for SINR-traffic-enabled JT CoMP-based schemes.

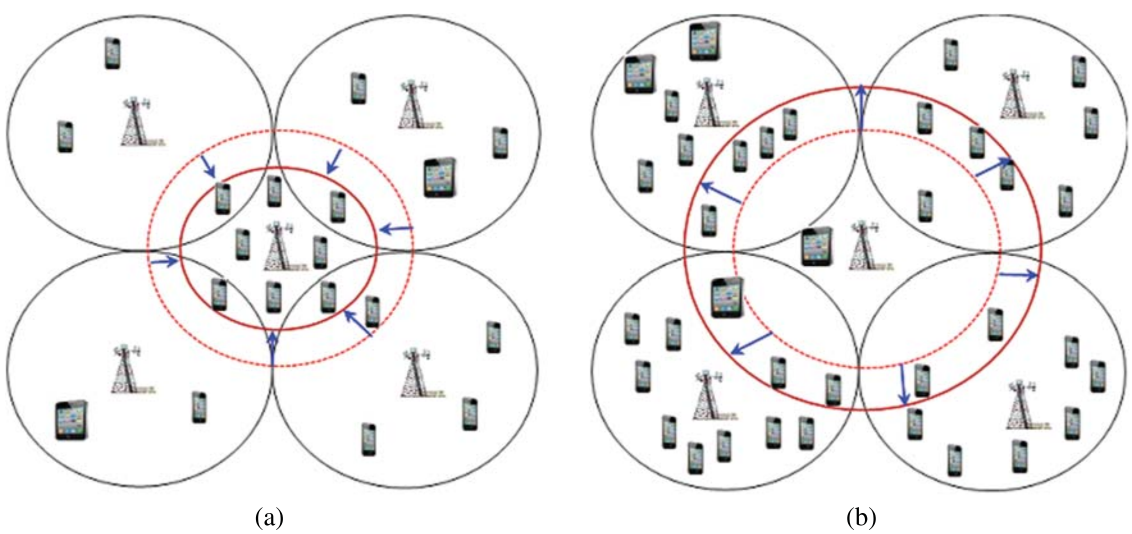

Figure 4: Concepts of cell zooming. (a) Central cell zoom in (b) central cell zoom out

SINR-traffic-aware cell zooming: According to CoMP theory, a BS provides the maximum SINR, offering the best-received signal intensity to users. Moreover, lightly loaded BSs could either zoom out to serve more incoming users or zoom in to go into sleep mode for energy saving depending on the network settings. Under JT CoMP transmission, the BSs are sorted in a two-tier cluster in descending order of SINR and ascending order of traffic demand. In other words, a user is served jointly with two BSs that offer peak SINR and the BS having the closest distance. Notably, the closest BS does not always provide the best signal quality due to severe attenuation through shadow fading. The zooming procedure that incorporated this technique is known as the SINR-traffic-aware scheme. If the current traffic is less than the threshold limit ($\chi < \chi_{th}$), then the load should be released, and UE access must be reallocated. Moreover, the other BS that provides the topmost SINR value is selected. Fig. 5 shows the pseudo code of the proposed JT CoMP-based cell zooming algorithm. Similarly, the algorithms for other methods can be described.

Initialize: $\mathcal{RB}$, $\chi_{i,j}$, $k\forall U$, $i\forall N$
for $j = 1 : T$
  for $i = 1 : N$
    Locations and Received power of U=$\chi_{i,j}\mathcal{RB}$ associated with $\mathcal{B}_i$ are updated
     Compute $\gamma_{k\forall i}$
      for $k = 1 : U$
       Sort $\gamma_{k\forall N}$ in descending order
       Read the neighboring traffic load for connection
       Associate UE_k to the BS_{n1} and BS_{n2} providing maximum SINR
         if β_i active, $S_{i,j} = 1$, $\chi_{i,j} < \chi_{th}$, $Z_{i,j} = 0$, and $C^a_{i,j} \neq \phi$
          Find $F_{i,j} \in C^a_{i,j}$
          Stop searching to neighboring acceptor BSs
          else β_i active, $S_{i,j} \neq \phi$, $\chi_{i,j} < \chi_{th}$, $Z_{i,j} \neq 0$, and $C_{i,j} = \phi$
          Find $F_{i,j} \in C^s_{i,j}$ such that $\chi_{i,j} \subseteq F_{i,j}$
          $U = \chi_{i,j}\mathcal{RB}$ associated with $\mathcal{B}_i$ are updated
         end if
         Assign available RBs to all active UEs
         Update $\chi_{i,j}$
      end for
  end for
end for

Figure 5: SINR–SINR-based traffic steering cell zooming algorithm

3 Performance Analysis

3.1 Simulation Setup

We presume the same power profiles for all 19 cells in two tiers, and UEs are assumed to be distributed randomly over the given geographical area. In addition, every single active user that occupies one RB is considered throughout the simulations. Tab. 3 shows a set of input parameters for simulations in the MATLAB environment.

3.2 Result Analysis

Fig. 6 depicts the variation of ECG with the cell zoom-out level for different UE-BS association schemes. All the user association methods follow a similar pattern to reach their minimum value with the increment of the zoom-out level. This finding signifies the improvement of energy expenses for the higher value of the zooming level. The distance-based user connection policy shows inferior performance compared with others. By contrast, the SINR-based scheme outperforms others. Notably, the ECG gap is apparently less significant between SINR and SINR-traffic-based methods. The reason is that the two BSs offering the best SINR and minimum existing traffic show almost close performance with the SINR technique at varying zooming levels. Notably, the SINR-based method resembles SINR–SINR, and distance–distance schemes can be represented as the distance only scheme; therefore, they are used interchangeably in this manuscript.

Table 3: Summary of simulation parameters [3]

Parameters	Value
RB bandwidth	180 kHz
System bandwidth, BW	5, 10, 15, 20 MHz (25, 50, 75, 100 RBs)
Carrier frequency, f_c	2.1 GHz
Duplex mode	FDD
Cell radius	1,000 m
BS transmission power	43 dBm
Noise power density	−174 dBm/Hz
Number of sectors	3
Number of antennas	2
Number of carriers	1
Reference distance, d_0	100 m
Path loss exponent, n	3.574
Shadow fading, σ	8 dB
Access technique, DL	OFDMA
Traffic distribution	Random

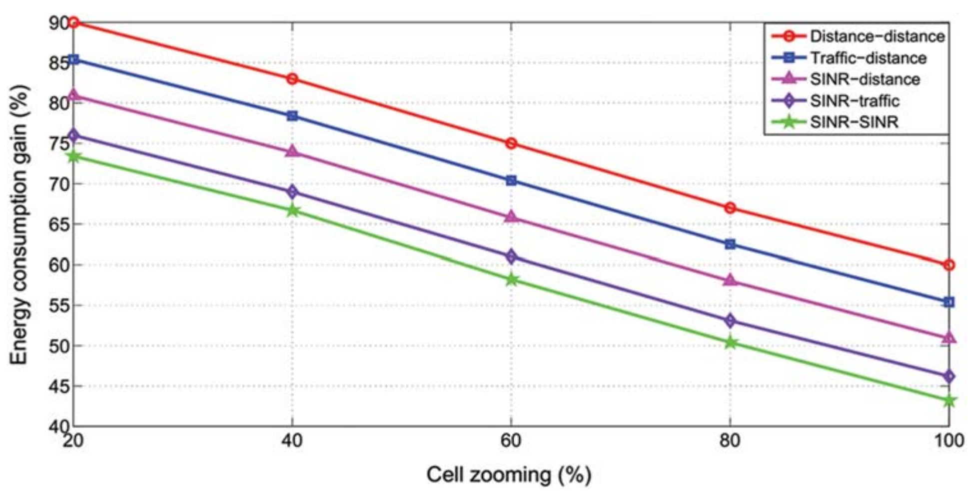

Figure 6: ECG *vs*. cell zooming level under different user association schemes

The energy-saving performance follows a similar pattern for all UE-BS association schemes with the zoom-out options as shown in Fig. 7. All the curves are up trending with the increment of zooming level, and the energy-saving gap is insignificant because of the similar ECG behaviors.

The energy-saving curve demonstrates the opposite trend of ECG with the percentage of zooming. However, the SINR-based scheme has excellent energy-saving capability over the conventional distance-based cell zooming mechanism. Similarly, in the ECG graph, the separation between SNIR and SNIR traffic-based schemes lies close together comparatively because both methods offer the best signal quality. Thus, a hybrid SINR–SINR-enabled zooming system is the preferred choice among others.

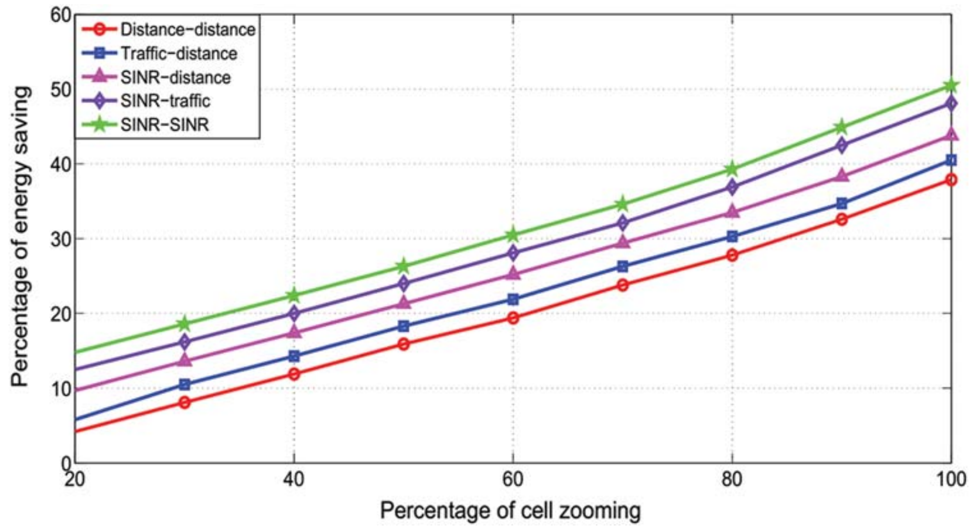

Figure 7: Comparison of energy saving *vs*. cell zooming level

Fig. 8 illustrates the comparison of throughput performance between JT CoMP-based cell zooming schemes with the conventional system, that is, non-CoMP-based systems. Notably, the throughput graph apparently follows the traffic demand shown in Fig. 3. According to the traffic load profile, the peak traffic arrivals occur at 8 PM when the maximum number of RBs is occupied. However, all the curves follow an identical pattern, and the distribution gap is substantial during peak traffic hours. Moreover, the gap is less significant for the SINR and SINR-traffic based schemes as explained beforehand. UE experiences better signal quality for the higher value of SINR resulting in higher throughput. The UE receives the best signal power under the SINR-based JT CoMP cell zooming scheme that exhibits better performance as shown in Fig. 8. Under the JT technique, the data received from two or more neighboring BSs to a particular UE lead to higher throughput performance.

Figs. 9 and 10 show a detailed comparison of EEI for different zooming schemes under 10 MHz. According to the definition of EEI presented in the performance metrics section, EEI is evidently a direct function of throughput. Notably, the SINR-based CoMP method provides the highest SE and EE, including the joint SINR enhancement and lower level of power consumption. The SINR-enabled zoom-out technique attains approximately 87.5% more EE than that of a non-CoMP-based tradition distance-aware system. Moreover, EEI shifts toward an upward direction with the increment of the zoom put level. As expected, the suggested framework follows the gradual improvement of EEI with the cell coverage level observed in Fig. 10. Thus, we can be safely inferred that the SINR CoMP-based method offers superior EEI performance.

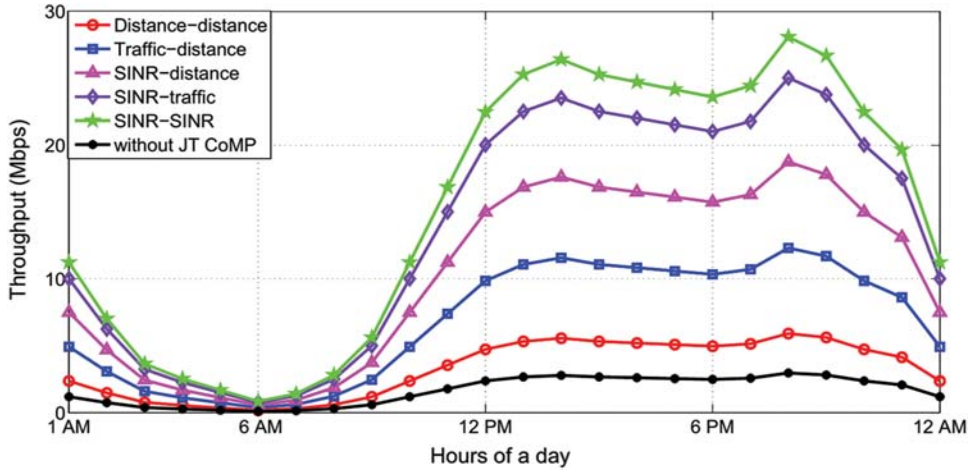

Figure 8: Comparison of throughput performance

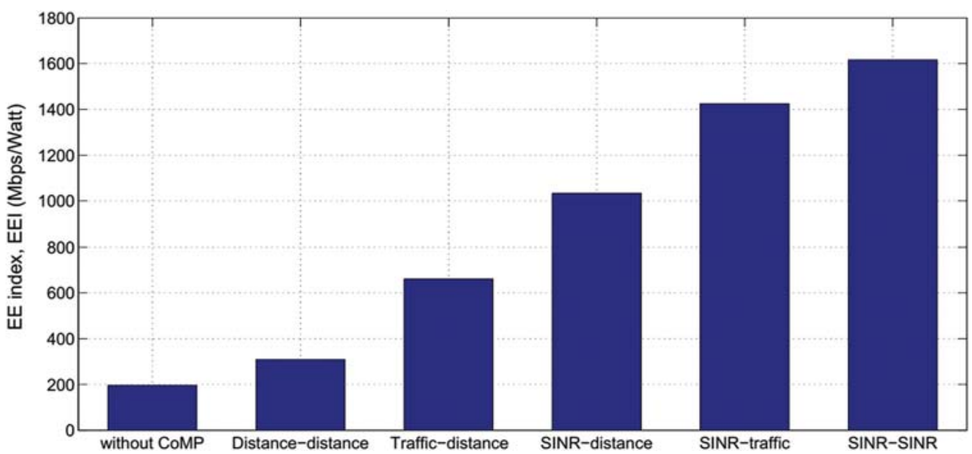

Figure 9: Comparison of EEI

Fig. 11 illustrates the EE performance with the system bandwidth for 2-kW installed solar capacity for each BS. In accordance with the definition, the scheme provides the peak throughput to uplift the EE. More RBs are allocated for the high system bandwidth. Therefore, EE curves start to increase in the upward direction to reach their maximum value identically as clearly seen from the figure. On the other hand, the SINR JT scheme offers the best utilization of RB in terms of maximum signal power to serve the associated UE.

Based on the aforementioned demonstration of Figs. 11, 12 illustrates the impact of cell zooming varying system bandwidth. A greater value of bandwidth and zooming level elevated EE performance significantly, that is, EE performance scaled with BW and zoom out level. The best system performance is obtained for the 20-MHz bandwidth and 100% cell zooming. However, the figure is derived for the SINR JT CoMP-based technique assuming that a 2-kW solar panel is installed in the BSs. Further analysis of the figure identifies that EE performance yields 63.7% better for the 20-MHz bandwidth than BW = 5 MHz and achieved 64.8% enhancement for 100% cell zooming.

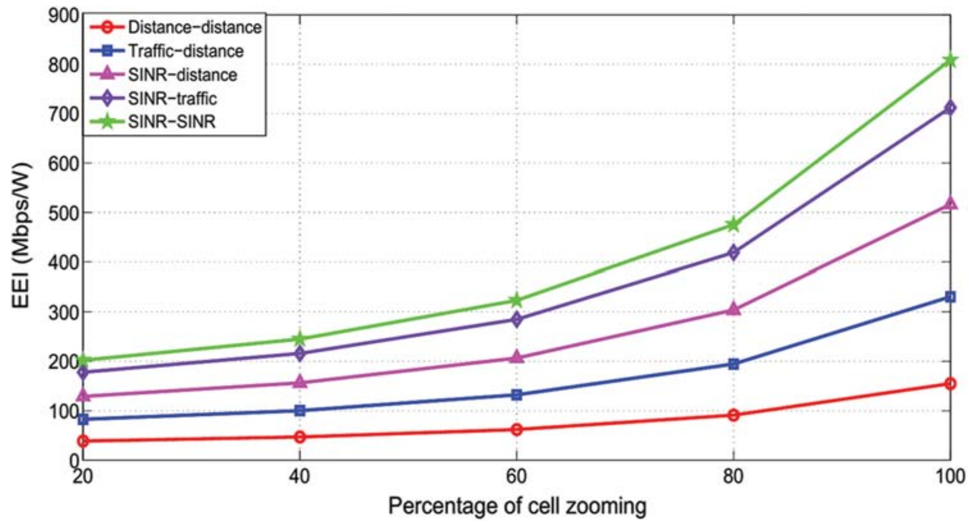

Figure 10: EEI evaluation *vs*. cell zooming varying UE association schemes

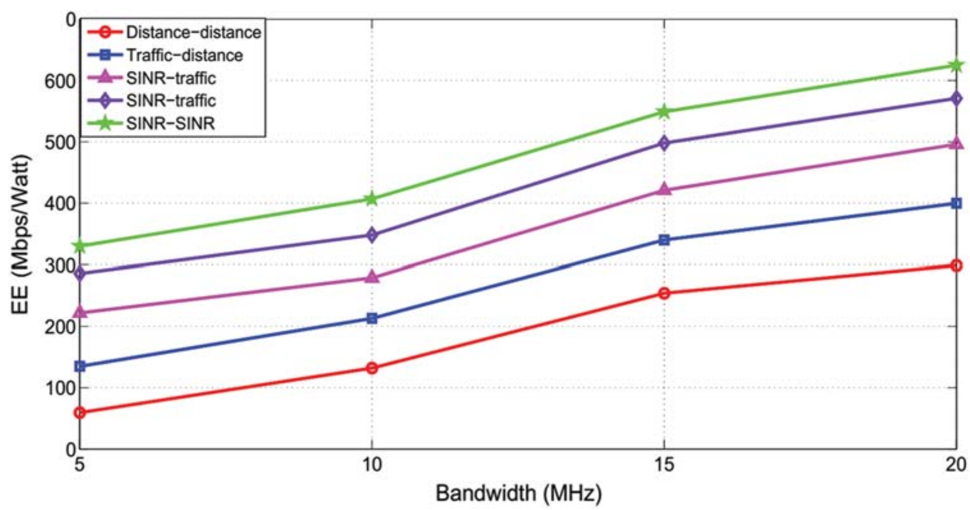

Figure 11: EE *vs*. system bandwidth

Fig. 13 presents the comparison of EE with the solar PV capacity demonstrating the performance of different user association schemes. As the solar capacity increases, the EE linearly scaled to reach the maximum point. Once again, the SINR-based scheme attains optimistic performance over all other schemes. For example, the SINR-based hybrid cellular system with 5 kW offers 32.4% more energy efficient than the PV = 4 kW capacity. Moreover, the cell zooming level has a considerable impact on EE as shown in Fig. 10, which is obtained for a 10-MHz SINR-enabled hybrid system. The rising value of SPV and zoom out forces the EE to increase the desired quality satisfaction.

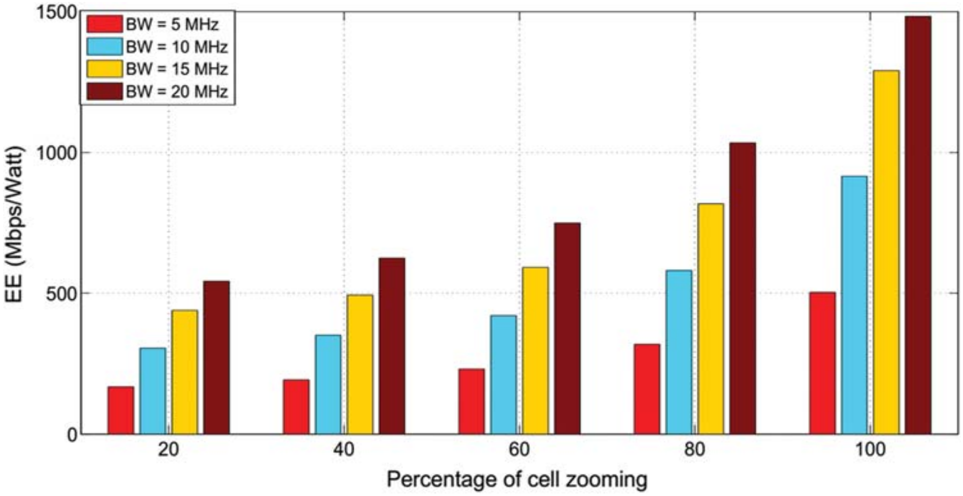

Figure 12: EE *vs*. zooming level varying bandwidth

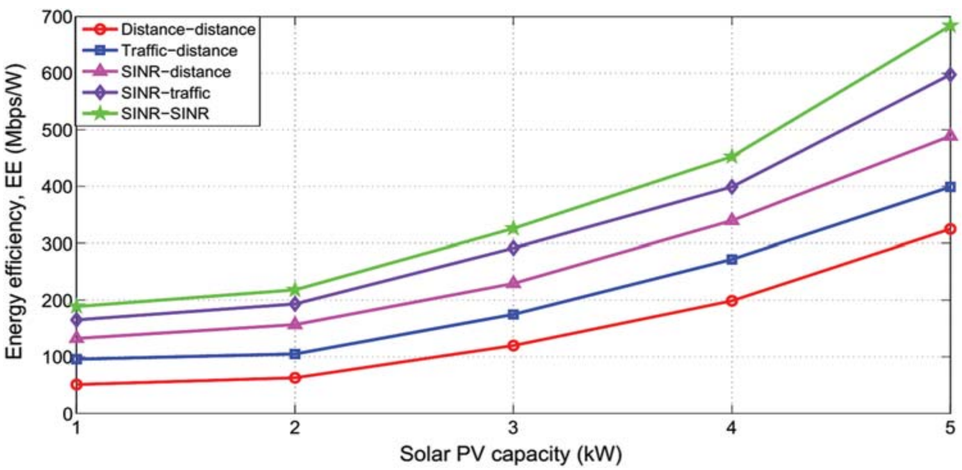

Figure 13: Variation of EE with installed PV capacity

Fig. 14 depicts a comprehensive comparison of the ESI with a load factor. Fig. 14 is derived for BW = 10 MHz and SPV = 2 kW capacity, where the proposed scheme is compared with the non-zooming condition. In addition, Fig. 12 is drawn from the SINR–SINR-enabled method for the given network settings. All the curves follow a similar fashion to reach the least values with the increment of load factor. This figure again signifies the optimistic behavior of the SINR-based cell zooming method in which ESI is maximum. For instance, the ESI performance attains 17.5% better performance for the SINR-based cell zooming scheme compared with the non-zooming scheme when LF = 0.5. In summary, the SINR-based JT CoMP cell zooming technique with a high bandwidth is the preferred choice in terms of energy-saving performance.

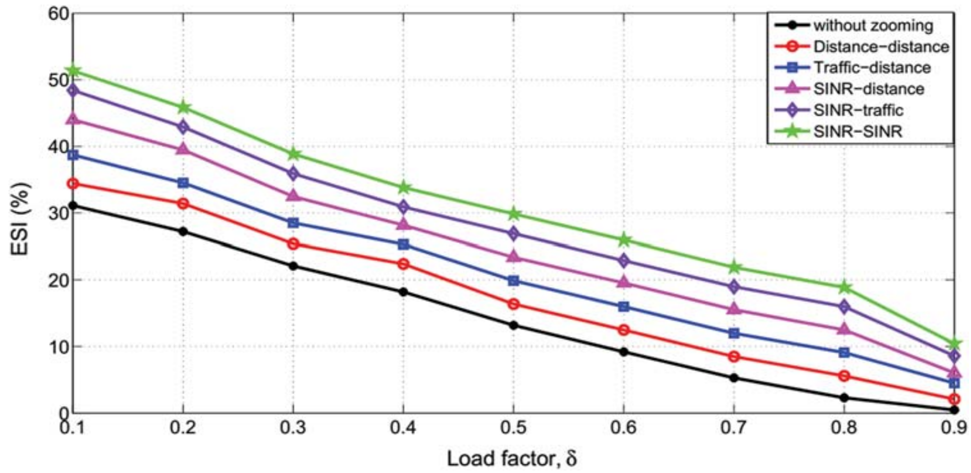

Figure 14: ESI performance *vs*. load factor

4 Conclusion

This study presents a joint coordination-based adaptive cell zooming algorithm for Cloud-RAN networks powered by hybrid supplies. A combined integration of JT CoMP-enabled cell zooming green C-RAN networks shows remarkable SE and EE performance with minimum energy consumption. In light of this, energy reduction and throughput have been analyzed for the envisioned C-RAN networks. The SINR-based UE-BS association technique exhibits superior EE performance by prioritizing solar energy consumption over traditional grid electricity. The proposed joint green policy has shown high throughput, SE, and ESI and low degradation of signal quality. The results reveal that the greater cell zooming level and higher PV capacity depict an enhanced system performance among different schemes. A noticeable impact of load factor and system bandwidth on the proposed framework regardless of the zooming level is observed. A JT CoMP-based system is 87% more energy-efficient and achieves 17.5% more energy-saving performance than a non-CoMP-based cell zooming method. In a word, the EE level predominantly depends on the network configurations.

Funding Statement: This work was supported by SUT Research and Development Funds and by Thailand Science Research and Innovation (TSRI). Also, this work was supported by the Deanship of Scientific Research at Prince Sattam bin Abdulaziz University, Saudi Arabia. In addition, support by the Taif University Researchers Supporting Project Number (TURSP-2020/77), Taif University, Taif, Saudi Arabia.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

References

[1] A. Jahid, M. S. Hossain, M. K. H. Monju, M. F. Rahman and M. F. Hossain, “Techno-economic and energy efficiency analysis of optimal power supply solutions for green cellular base stations,” *IEEE Access*, vol. 8, no. 2, pp. 43776–43795, 2020.

[2] E. Masero, L. A. Fletscher and J. M. Maestre, “A coalitional model predictive control for the energy efficiency of next-generation cellular networks,” *Energies*, vol. 13, no. 24, pp. 6546–6566, 2020.

[3] M. S. Hossain, A. Jahid, K. Z. Islam, M. H. Alsharif, K. M. Rahman *et al.,* "Towards energy efficient load balancing for sustainable green wireless networks under optimal power supply," *IEEE Access*, vol. 8, no. 3, pp. 200635–200654, 2020.

[4] M. S. Hossain, A. Jahid, K. Ziaul Islam, M. H. Alsharif and M. Rahman, "Multi-objective optimum design of hybrid renewable energy system for sustainable energy supply to a green cellular networks," *Sustainability*, vol. 12, no. 9, pp. 3536–3556, 2020.

[5] M. S. Hossain, A. Jahid, K. Z. Islam and M. F. Rahman, "Solar PV and biomass resources-based sustainable energy supply for off-grid cellular base stations," *IEEE Access*, vol. 8, no. 2, pp. 53817–53840, 2020.

[6] A. Jahid, K. H. Monju, S. Hossain and F. Hossain, "Hybrid power supply solutions for off-grid green wireless networks," *International Journal of Green Energy*, vol. 16, no. 1, pp. 12–33, 2019.

[7] M. Elhattab, M. A. Arfaoui and C. Assi, "A joint CoMP C-NOMA for enhanced cellular system performance," *IEEE Communications Letters*, vol. 24, no. 9, pp. 1919–1923, 2020.

[8] A. Jahid, A. B. Shams and M. F. Hossain, "Dynamic point selection CoMP enabled hybrid powered green cellular networks," *Computers and Electrical Engineering*, vol. 72, no. 3, pp. 1006–1020, 2018.

[9] M. Wakaiki, K. Suto, K. Koiwa and T. Zanma, "A control-theoretic approach for cell zooming of energy harvesting small cell networks," *IEEE Transactions Green Communications and Networking*, vol. 3, no. 2, pp. 329–342, 2019.

[10] H. Jiang, S. Yi, L. Wu, H. Leung, Y. Wang *et al.,* "Data-driven cell zooming for large-scale mobile networks," *IEEE Transactions on Network and Service Management*, vol. 15, no. 1, pp. 156–168, 2018.

[11] S. Zhou, J. Gong, Z. Yang, Z. Niu and P. Yang, "Green mobile access network with dynamic base station energy saving," *ACM MobiCom*, vol. 9, no. 26, pp. 10–12, 2009.

[12] E. Oh, K. Son and B. Krishnamachari, "Dynamic base station switching-on/off strategies for green cellular networks," *IEEE Transactions on Wireless Communications*, vol. 12, no. 5, pp. 2126–2136, 2013.

[13] S. Luo, R. Zhang and T. J. Lim, "Optimal power and range adaptation for green broadcasting," *IEEE Transactions on Wireless Communications*, vol. 12, no. 9, pp. 4592–4603, 2013.

[14] J. Xu, L. Duan and R. Zhang, "Energy group buying with loading sharing for green cellular networks," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 4, pp. 786–799, 2016.

[15] M. Hossain, K. Ziaul Islam, A. Jahid, K. M. Rahman, S. Ahmed *et al.,* "Renewable energy-aware sustainable cellular networks with load balancing and energy-sharing technique," *Sustainability*, vol. 12, no. 22, pp. 9340–9360, 2020.

[16] A. Jahid, M. K. H. Monju, M. E. Hossain and M. F. Hossain, "Renewable energy assisted cost aware sustainable off-grid base stations with energy cooperation," *IEEE Access*, vol. 6, no. 3, pp. 60900–60920, 2018.

[17] J. Gong, J. S. Thompson, S. Zhou and Z. Niu, "Base station sleeping and resource allocation in renewable energy powered cellular networks," *IEEE Transactions on Communications*, vol. 62, no. 11, pp. 3801–3813, 2015.

[18] Y. Mao, G. Yu and Z. Zhang, "On the optimal transmission policy in hybrid energy supply wireless communication systems," *IEEE Transactions on Wireless Communications*, vol. 13, no. 11, pp. 6422–6430, 2014.

[19] J. Wu, Y. Bao, G. Miao, S. Zhou and Z. Niu, "Base-station sleeping control and power matching for energy-delay tradeoffs with bursty traffic," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 5, pp. 3657–3675, 2016.

[20] L. Suárez, L. Nuaymi and J.-M. Bonnin, "Energy-efficient BS switching-off and cell topology management for macro/femto environments," *Computer Networks*, vol. 78, no. 3, pp. 182–201, 2015.

[21] L. Suárez, L. Nuaymi, D. Grace, S. Rehan and J.-M. Bonnin, "A multi-criteria bs switching-off algorithm for 5G heterogeneous cellular networks with hybrid energy sources," *Transactions on Emerging Telecommunications Technologies*, vol. 27, no. 7, pp. 923–938, 2016.

[22] G. H. Carvalho, I. Woungang, A. Anpalagan and E. Hossain, "Qos aware energy-efficient joint radio resource management in multi-RAT heterogeneous networks," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 8, pp. 6343–6365, 2016.

[23] S. Zhang, N. Zhang, S. Zhou, J. Gong, Z. Niu *et al.,* "Energy-aware traffic offloading for green heterogeneous networks," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 5, pp. 1116–1129, 2016.
[24] T. Han and N. Ansari, "A traffic load balancing framework for software-defined radio access networks powered by hybrid energy sources," *IEEE/ACM Transactions on Networking*, vol. 24, no. 2, pp. 1038–1051, 2016.