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RESEARCH ARTICLE

Energy-Efficient Hybrid Powered Cloud Radio Access Network (C-RAN) for 5G

MST. RUBINA AKTAR[1,2], MD. SHAMIM ANOWER[2], MD. ZAHURUL ISLAM SARKAR[2], (Member, IEEE), ABU SADAT MD. SAYEM[3,4], MD. RASHEDUL ISLAM[1], ALLAMA IQBAL AKASH[1], MST. RUMANA AKTER RUME[1], GHOLAMHOSEIN MOLOUDIAN[5], (Member, IEEE), AND ALI LALBAKHSH[3,4], (Senior Member, IEEE)

[1]Department of Electrical and Electronic Engineering, Bangladesh Army University of Science and Technology (BAUST), Nilphamari 5300, Bangladesh
[2]Department of Electrical and Electronic Engineering, Rajshahi University of Engineering and Technology, Rajshahi 6204, Bangladesh
[3]School of Engineering, Macquarie University, Sydney, NSW 2109, Australia
[4]School of Electrical and Data Engineering, University of Technology Sydney, Ultimo, NSW 2007, Australia
[5]Tyndall National Institute, University College Cork, Cork, T12 R5CP Ireland

Corresponding authors: Ali Lalbakhsh (ali.lalbakhsh@mq.edu.au) and Gholamhosein Moloudian (gh.moloudian@tyndall.ie)

ABSTRACT Owing to the ever-increasing energy consumption, energy efficiency (EE) is an important parameter for next generation 5G network. The Cloud Radio Access Network (C-RAN) is a viable solution for tackling 5G network problems in an energy-efficient manner. Integrating renewable energy with C-RAN can be a powerful tool for reducing operating costs and carbon dioxide emission. But, the regional unpredictability and intermittency nature of renewable energy can result in energy outages and worsening the service quality. As a consequence, the most reliable way is to combine commercial grid supplies with renewable energy. In this paper, we proposed a network model for the downlink C-RAN with hybrid power supplies. The goal of the proposed hybrid supply with solar and grid energy collaboration is to optimize the use of renewable solar energy by reducing grid Power Consumption (PC) and, most significantly, enhancing energy efficiency and preserving service quality. A comprehensive analysis is performed to evaluate EE performance of the proposed C-RAN under a variety of network settings. The numerical results affirm the proposed C-RAN models establishing a significant improvement in network EE compared to the conventional one.

INDEX TERMS Energy efficiency, hybrid supplies, renewable energy, C-RAN, 5G.

I. INTRODUCTION

With a significant surge in mobile subscriptions and bandwidth-hungry apps and services, mobile data traffic has grown quickly and spectacularly in recent years [1]. According to an analysis, the number of network-based equipment subscribers globally increased from 4.5 billion in 2013 to 5.4 billion in 2017, with the number expected to reach 6.2 billion by 2023 [2]. The massive traffic demand on cellular networks requires an increase in network capacity [3]. According to [4] the ICT sector consumes 10% of overall energy, with mobile networks accounting for 2-3.5 percent. To improve cellular network performance, mobile network operators must be able to meet this demand with a new approach and new value-added services. Because of the inexorable growth of mobile traffic, it is expected to exacerbate a worldwide critical energy consumption challenge that has surpassed all expectations. Mobile operators are seeking new ideas to address the growing need for high data rates, large capacity, high security, and the fastest feasible connectivity. Novel designs, innovative digital signal processing systems and protocols are always welcome [5]. Energy consumption growth of the fifth-generation (5G) mobile network infrastructure can be significant due to the increased traffic demand for a massive number of end-users with increasing traffic volume, user density, and data rate [6]. By 2028, 5G networks are expected to achieve widespread adoption in consumer and enterprise ecosystems,

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resulting in a huge increase in energy consumption [7]. Power consumption of the 5G network is expected to soar due to active network elements like energy-hungry baseband units, remote radio heads, small cells, and core networks [7]. The surge in wireless network energy consumption is putting tremendous strain on power grid supplies, as well as rising CO2, which has been identified as a severe danger to environmental protection and long-term development [8]. In a traditional radio access network, the Base Station (BS) unit consumes around half of the energy, with the remainder being consumed by other radio unit components such as amplification, processing, and cooling [9]. Decreasing cell size can be an effective strategy to boost system capability by enhancing the reuse of radio frequency to satisfy the massive amount of traffic loads on cellular networks. However, in cellular networks, smaller cells result in higher costs due to construction and operational issues, as small cells necessitate a huge number of BSs to give continuous coverage areas comparable to macro cells. The number of traffic changes throughout the time and varies by location. In office (business) zones, traffic demand is higher during the day. On the other hand, traffic demand in residential areas is higher at night. The rate of change is determined by the location (i.e., urban, suburban, rural). Current cellular networks place base stations in strategic locations to satisfy traffic demands. As a consequence, there will be a higher number of BSs needed, and costs are rising significantly.

A new RAN design, such as the Cloud Radio Access Network (C-RAN), could be a feasible solution to the above issue was first introduced in [10]. C-RAN is made up of a centralized baseband unit (BBU) and remote radio head (RRH) that uses the same radio frequency [11]. The BBU resides in a BBU-pool, and it does all the controlling and processing activities over a virtualized RAN platform. RRHs are geographically circulated and linked to the User Entities (UEs) over an RF signal and to the centralized BBU through an optical fronthaul [12]. The centralized BBU controls RRHs via a high-bandwidth, low-cost optical link. Reduced grid usage through the use of renewable energy harvesting technologies could be a feasible alternative for finding a reliable solution to the problem of greater power consumption [13]. It has emerged as a most promising alternative for lowering the global warming effect of carbon footprint, and it has the potential to phase out consumption from traditional grid supply at a rapid rate, resulting in increased energy efficiency. Most cellular network companies around the world are currently installing renewable energy generators and concentrating on infrastructure to make networks greener using low-cost alternatives [14]. Renewable energy, also known as green energy, is substantially less expensive than traditional grid energy and has no negative environmental impact because it emits no carbon. As a consequence, it becomes the most reliable.

Despite the potential benefits of RE harvesting technology, the intermittency and variability of renewable energy (RE) sources may not provide a consistent and reliable power supply throughout the day, lowering system overall performance and reliability [15]. We believe that an aggregate technology, which combines renewable energy with traditional grid power, is the most promising option or methodology for reliably powering cellular infrastructure. The authors in [16] lead to minimize the consumption of energy in the MEC system with energy harvesting (EH) devices, no data collaboration and power allocation has been explored. In [17], the author focuses on reducing total power usage by utilizing power management and RE sharing while ignoring data collaboration. In [18] Younis et. al, proposed a novel resource allocation solution that optimizes the energy consumption of a C-RAN. The communication resources depend on multiple parameters including the number of allocated Physical Resource Blocks (PRBs), resource blocks allocated to the users (UEs) as well as on the Signal-to Noise Ratio (SNR) and the Modulation and Coding Scheme (MCS) index. Hence, they considered the BBU power consumption as a function of the parameters such MCSs, PRB, SNRs, UEs, etc. The authors in [19] have improved the network EE by utilizing data cooperation rather than energy harvesting and sharing. Authors in [20] proposed an energy efficiency optimization jointed resource allocation for delay-aware traffic in fronthaul constrained C-RAN. The simulation results showed that the explored optimization algorithm had superior energy efficient performance, which was improved by 15% and 30% compared to BBU allocation decomposition model and BBU scheduling model, respectively. In [21], authors comprehensively discussed different EE improvement techniques that were promising for green communications. Also, they had reformulated the power consumption and allocation models for the optimization of green energy utilization, taken into consideration the random nature of the harvested energy in the network. Simulation results showed that the network EE was enhanced when the resource allocation algorithm was exploited. Authors in [22] investigated a long-term energy efficiency (EE) optimization problem in hybrid energy supplied C-RAN. Theoretical analysis and simulation results demonstrated the performance improvement of the energy cooperation. A dynamic point selection coordinated multipoint based adaptive load balancing scheme for C-RAN networks was examined in [23]. Extensive system-level simulations demonstrated that the suggested framework increased EE index by 32%. The EE performance optimization in C-RAN supplied by hybrid energy sources was analyzed in [24]. Simulation results confirmed that the demonstrated resource allocation solution could provide 35% higher energy efficiency for the C-RAN compared to solutions that do not consider hybrid energy power supply. In addition, authors in [25] have proposed a combinatorial optimization algorithm to maximize the system EE with the aim to reduce grid power consumption (GPC) and the demonstrated method reduced energy by nearly 20% and increases EE around 10% during harvested energy scarcity among the BSs. But, this outcome ignores the presence of energy storage devices and part of the captured energy may be wasted if none of the base stations requires it at a given time.

Unlike the existing work, in this paper, we proposed a C-RAN network with hybrid power supplies aiming to maximize solar energy utilization leading to higher energy efficiency as well as a reduction of conventional grid energy utilizing the energy cooperation and energy storage mechanism. Extensive simulations are run to assess the proposed model's energy efficiency (EE) performance across a variety of network circumstances. In our explored method, the experimental results demonstrate that in comparison to conventional C-RAN, the proposed system with 4kW module capacity achieves maximum EE of 91% and 88% for residential areas and 94% and 90 % for office areas while the transmitting power are 20 W and 40 W, respectively.

The notable contributions of this research are given below,

- This research proposes a novel framework to improve the EE of the next-generation 5G cellular network C-RAN by employing a hybrid power supply for both BBU pool and RRHs. Under the proposed network, solar energy is considered as the primary source, whereas traditional grid energy is considered as the secondary source for operating BSs in the case of solar energy shortage to provide uninterrupted service to the UEs. Then, an energy sharing algorithm for the optimal usage of solar energy i.e., diminishing the conventional grid consumption is developed to improve the EE of the proposed network.
- The intermittency nature of solar energy generation as well as tempo-spatial diversity of mobile traffic performs an important role in the development of green networking strategies. The performance of proposed system is also significantly impacted by BS power consumption models. The network scenario is made close to realistic by taking into account all of these aspects in the research that is being offered.
- The advocated hybrid energy supply system is then investigated for both on grid power consumption and EE of the network under two different traffic conditions (residential and office areas) with two different transmitting power (20 W and 40 W) and four different solar generation capacities (1 kW, 2 kW, 3 kW and 4 kW).
- We developed a mathematical model for evaluating the on grid power consumption and EE performance of the proposed C-RAN.
- A MATLAB based simulation platform is developed for carrying out the extensive simulations.
- Lastly, the EE performance of the proposed C-RAN will be compared with that of the conventional C-RAN.

II. SYSTEM MODEL

A. NETWORK LAYOUT

The renewable energy-based downlink C-RAN adopted in this paper as illustrated in Figure 1. It comprises a BBU pool and a radio unit (RUs). The radio units (RUs) are made up

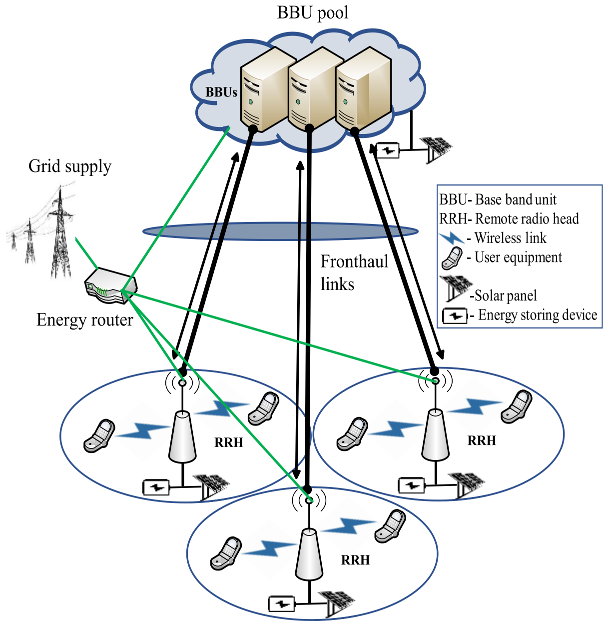

FIGURE 1. Proposed C-RAN model.

of N remote radio heads (RRH) that work together to support M users. Let, U = {m1, m2, m3. . . .,M} and R = {n1, n2, n3. . . . . . ,N} are the set of user and RRH respectively. All of the RRHs (for example, three RRHs) are connected to BBU pool (for example, three BBUs) via high-bandwidth wired front-haul lines. A single BBU can handle one or more RRHs, as long as the data is within its capacity. The central controller or BBU pool distributes data to various RRHs based on the energy obtainability at RRHs and the signal requirements of users. Through an energy sharing router, network entities and devices are also linked to the grid energy supply. The main functions of energy router are the interconnection of energy unit and energy distribution. The grid power is supplied to the network entities through energy router. For efficient management of the energy supply and demand in the power grid, energy routers are required which dynamically adjust the energy distribution. Integration of solar PV system as a RE source in the architectures is the key feature of the proposed C-RAN. The BBU pool and each RRH of C-RAN are powered by hybrid supplies, combining solar module with storage facility and grid supply.

Each of them is also connected to a storage device, such as a battery cell, which allows them to store excess electricity for later use. The RRHs is switched on to grid supply in the absence or insufficiency of stored energy. An energy usage algorithm is developed and integrated in the architectures for making decision whether the RRH is powered by only solar module, only grid or both. A MATLAB based simulation is developed for investigating the on grid power consumption as well as the main performance metric EE of the proposed network. The realistic 24-hour traffic and solar energy generation profiles with tempo-spatial diversity is considered in the simulations. Performance of the proposed network models is investigated varying system parameter such as RRH configurations (e.g., transmit power) and solar module capacity.

B. TRAFFIC MODEL

The traffic distribution in wireless networks shows both spatial and temporal variability [26]. The number of subscribers or customers varies over time, indicating that mobile traffic is temporally diverse. Furthermore, the number of data-traffic on each BS varies, indicating the spatial diversity of traffic by location. For each RRH, two typical traffic profiles are used; one is for the residential area (taken from [27]) as shown in Figure 2 and another one is for the office area (taken from [28]) as shown in Figure 3. We considered up to 50 users per cell where the users are randomly distributed. Whenever there is maximum number of users (about 50) under an RRH, this is considered as 100% traffic. The arrival of user entity (UE) at a BS follows Poisson distribution. The power consumption at a BS is proportional to the traffic arrival rate (λ). The probability of "m" number of UE arrived at "τ" interval of time is expressed as [29]:

$$P(m) = \frac{(\lambda\tau)^m e^{-\lambda\tau}}{m!} \tag{1}$$

The probability of one call arrived at the RRH within a small interval of time $\Delta\tau$ is expressed as [29]:

$$\begin{aligned} P(1) &= \frac{(\lambda\Delta\tau)^m e^{-\lambda\Delta\tau}}{1!} \\ &= (\lambda\Delta\tau)^m e^{-\lambda\Delta\tau} \end{aligned} \tag{2}$$

It is worth to mention that in the considered traffic load distributions, the two traffic profiles are taken from two different geographical areas, as a result, they have the same peak at 5 PM. Further research investigations can be explored considering two traffic profiles for the same geographical area.

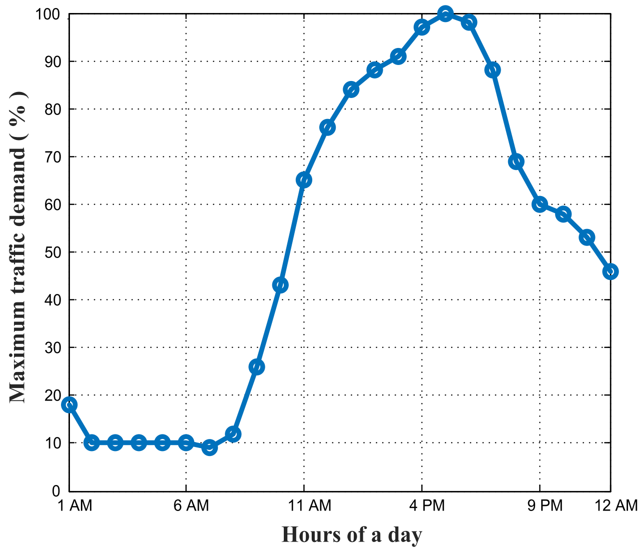

FIGURE 2. Traffic load for 24 hours of a residential area [27].

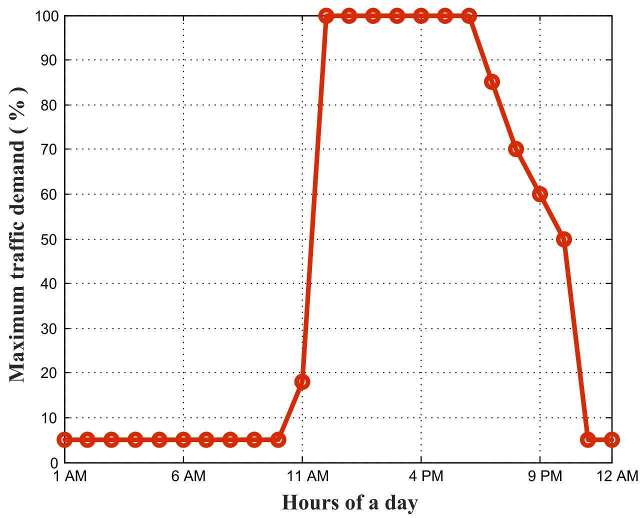

FIGURE 3. Traffic profile for 24 hours of an office area [28].

C. POWER CONSUMPTION MODEL

1) CONVENTIONAL C-RAN POWER MODEL

The baseline power model for conventional C-RAN was derived from [30], and the power consumption of an evolved Node B may be approximated by,

$$P_{enodeB} = P_{BBU} + P_{RRH} \tag{3}$$

Here, P_{BBU} and P_{RRH} are the power consumption of BBU and RRH respectively.

The RRH's power consumption can be stated as the sum of dynamic consumption and static consumption. The static power does not depend on traffic load but the dynamic PC is varied linearly with the traffic loading parameter (γ). Figure 4 shows that while the BS is working at transmission power (p_{MAX}), the maximum supply power (p_1) is reached. The parameter p_0 is the static power consumption. On the other hand, a RRH without any traffic load enters into sleep mode with lowered consumption, (p_{sleep}). Mathematically, the total power dissipation for RRH can be as [1],

$$p_{RRH} = \begin{cases} N_{TR}\left(p_1 + \Delta_p p_{MAX}(\gamma - 1)\right) & 0 < \gamma < 1 \\ N_{TR} p_{sleep} & \gamma = 0 \end{cases} \tag{4}$$

where, $p_1 = p_0 + \Delta_p p_{MAX}$, N_{TR} is the number of transceivers per RRH and γ is the traffic load, with the value of $\gamma = 1$ indicating a fully loaded system and the value of $\gamma = 0$ indicating a system that is idle. Δ_p refers to power gradient, i.e the slope of the load-dependent power (as indicated in Figure 4). Table 1 displays the parameters [1] [8].

The following formula is used to compute the overall power for the conventional C-RAN ($P_{C-C-RAN}$) covering an area with N number of BSs.

$$P_{C-C-RAN} = N.P_{enodeB} \tag{5}$$

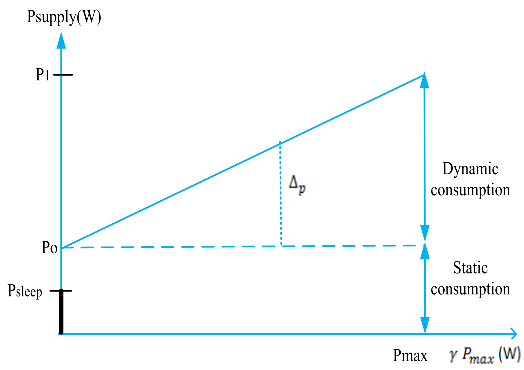

FIGURE 4. Load-dependent power model [31].

TABLE 1. Power consumption parameter [1] [8].

N_{TRX}	$P_{max}(W)$	$P_o(W)$	Δp	$P1(W$	P_{BBU} (W)	P_{sleep} (W
1	20.0	84	2.8	140	29.5	56
1	40.0	84	2.8	196	29.5	56

2) PROPOSED C-RAN POWER MODEL

The proposed C-RAN power ($P_{P-C-RAN}$) model consists of three parts: (i) Pool power (P_P), (ii) Fronthaul link power (P_L), and (iii) RRH power (P_R). Mathematically,

$$P_{P-C-RAN} = P_P + P_L + P_R \tag{6}$$

a: POOL POWER CONSUMPTION

The cooling power (P_{cool}) and the sum of active BBUs PC (P_{BBUi}) are used to determine the BBU pool power (P_p). It can be written as,

$$P_P = P_{cool} + \sum\nolimits_{i=1}^{M} P_{BBUi} + P_{cf} \tag{7}$$

The P_{BBUi} can be given as follows [32],

$$P_{BBUi} = P_{Static}^{BBUi} + \Delta_p^{BBUi}.P_{max}^{BBUi} + \beta_{BBUi} \tag{8}$$

where, P_{static} refers to power usage that is unaffected by the load and β_{BBUi} denotes the resource utilization factor of i^{th} BBU. Any BBU from the BBU pool can control the RRHs. Based on traffic conditions or user demand, the BBU-RRH allotment can be dynamically modified. P_{cf} stands for common framework power, which includes backhaul transmission, lighting, and site monitoring solutions [33].

$$P_{cf} = P_{Backhaul} + P_{lightning} + P_{monitoring} \tag{9}$$

b: RRH POWER CONSUMPTION

The total PC of RRH can be calculated through this equation,

$$P_R = \sum\nolimits_{r=1}^{R} \left(P_{static} + \Delta_p^{RRHr}.P_{max}^{RRHr}.\gamma^{RRH} \right) \tag{10}$$

where, Δ_p^{RRHr} refers to power gradient for r^{th} RRH, P_{max}^{RRHr} denotes the maximum transmit power of r^{th} RRH and γ^{RRH} is the traffic load of r^{th} RRH. Table 1 lists the network parameters used in our simulation. The [25] is used to derive the power values.

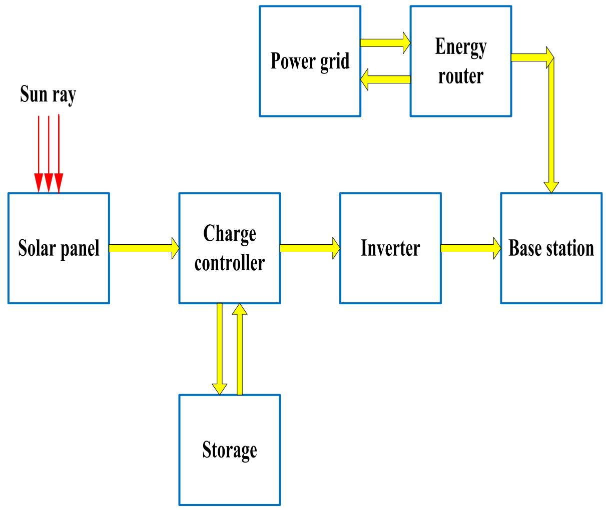

FIGURE 5. Block diagram of a hybrid energy power base station.

c: FRONT HAUL LINK PC

The front-haul link is the connection that connects numerous RRHs to the BBU pool. Optical fiber is used as the front-haul link and [34] is used to calculate the fiber's power budget. The power for a 40km fiber connection is approximately 8.33 dBW using these parameters.

D. HYBRID ENERGY MODEL

In the proposed network, we consider that the BS has its own RE system (solar). At the same time, the BS is also connected to the grid for power supply. Therefore, BS uses hybrid energy, namely grid and solar energy.

Figure 5 shows the reference design of a hybrid energy power base station. RE generation is the utmost efficient way to reduce grid power usage and greenhouse gas emissions. Solar Photovoltaic (PV), a green energy harvester, is positioned near the BBU pool and each RRH.

Figure 6 represents the average hourly solar energy generation of 1 kW, 2 kW, 3 kW, and 4 kW solar panels. Solar energy generation appears to begin at 6:00 AM. The amount of energy produced continues to rise until it reaches its maximum or peak at 1:00 PM. After 1.00 PM, energy production begins to decline and ends at about 6:00 PM. Seasonal, weather, and climate changes all affect solar energy production, so this may not always provide enough energy to the system. In that circumstance, grid electricity is essential to keep the system running and avoid outages and potential dependability issues.

E. ENERGY SHARING DYNAMICS

The proposed system model can draw energy from either renewable (RE) or grid-supplied sources. Let, E_n(t) be the

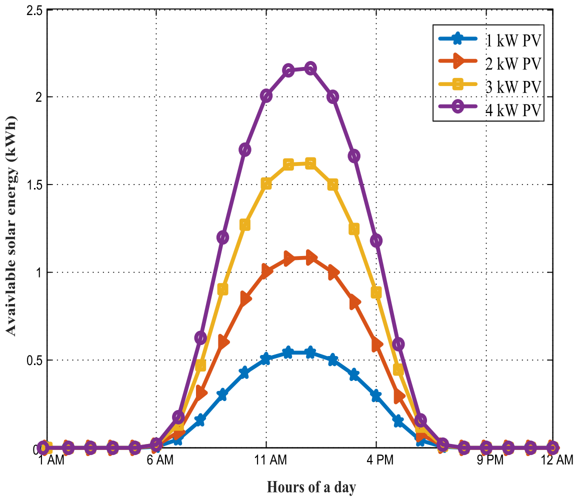

FIGURE 6. Average hourly solar energy generation.

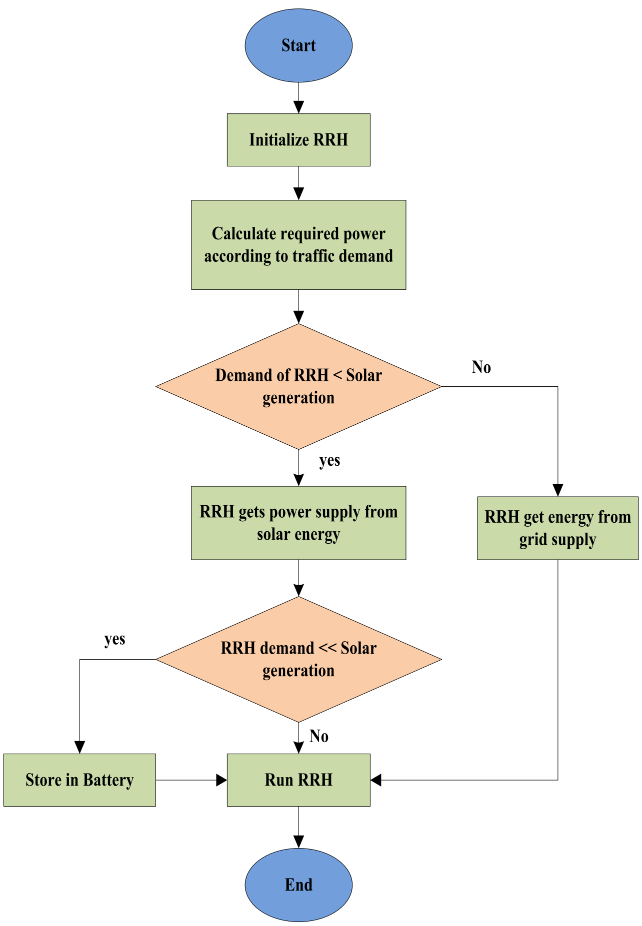

FIGURE 7. Energy sharing algorithm.

amount of solar energy received by the n^{th} RRH in time period t.

In each time slot, the following green energy constraint applies:

$$E_n(t) \leq \varepsilon_n(t) \leq \varepsilon_{max} \tag{11}$$

TABLE 2. Pseudo code for proposed energy sharing algorithm.

Step 1: Initialize: $\psi_n(t)$ and α
Step 2: List N of all RRHs
Step 3: Obtain the green storage energy $\psi_n(t)$ at time (t)
Step 4: Find the demand energy $\delta_n(t)$ for each RRH
Step 5: if (storage energy $\psi_n(t)$> demand energy $\delta_n(t)$)
$p_s(n,t) = \delta_n(t)$ and $p_g(n,t) = 0$
// $p_s(n,t)$ is the green solar power utilized by the nth RRH for serving its UEs and $p_g(n,t) = p_{in}(n,t) - p_s(n,t)$ is the on-grid energy consumption in nth RRH at time t where $p_{in}(n,t)$ is the required total power in nth RRH at time t.
Step 6: Calculate the remaining storage energy, $s_n(t) = \psi_n(t) - \delta_n(t)$
Step 7: else take energy from grid supply
Step 8: calculate $p_g(n,t) = \delta_n(t) - s_n(t)$
Step 9: $\delta_n(t) = p_g(n,t)$
Step 10: Stop the algorithm

The amount of ambient energy is denoted by $\varepsilon_n(t)$. The value of $\varepsilon_n(t)$ diametrically changes [35], which is restricted by ε_{max}, due to the effect of surrounding changes. If $\psi_n(t)$ denotes the n^{th}RRH energy storage at time t, then each time slot is occupied by the following solar energy saving [35],

$$\psi_n(t) = \alpha\psi_n(t-1) + E_n(t) - \delta_n(t) \tag{12}$$

where, δ_n(t) denotes the demand energy of a specific RRH. After each time slot, the factor indicates the proportion of leftover solar storage energy, which is bounded with $0 \leq \alpha \leq 1$.

The following are the solar and grid energy consumption of the n^{th} RRH in different conditions:

Case 1: $\psi_n(t) \geq \delta_n(t)$, then the n^{th} RRH will utilize its own energy, which is stored in battery cells or storage and the system model will not require grid electricity. After meeting demand, the total storage energy remaining can be stated as [35],

$$s_n(t) = \psi_n(t) - \delta_n(t) \tag{13}$$

Case 2: $\psi_n(t) \leq \delta_n(t)$, then the n^{th} RRH will use grid energy. In this instance, the nth RRH's grid usage can be represented as [35],

$$s(t) = \delta_n(t) - \psi_n(t) \tag{14}$$

The energy sharing algorithm is shown in Figure 7. The Pseudo codes of the energy sharing algorithm for n^{th} RRH is presented in Table 2.

F. PERFORMANCE METRICS

The EE metric, in particular, assesses data rate, or how effectively data can be transported for a given amount of

TABLE 3. Simulation parameter [8] [9].

Parameters	Values
Cell layout	Hexagonal
Cell radius	1000 m
Bandwidth, BW	10 MHz
Carrier frequency, fc	2 GHz
Cooling power, P_{cool}	500 Watt
Lighting power, $P_{lighting}$	50 Watt
Backhaul power, $P_{backhaul}$	200 Watt
Monitoring power, $P_{monitoring}$	50 Watt
Noise power, σ	-141dBm/Hz

energy. The smaller the power usage, the higher the energy efficiency of the system's operation. The EE for the proposed RE-based C-RAN is the ratio of total throughput to the grid power utilized by the network.

The total throughput C_t of the system can be written as [35],

$$C_t = \sum_{m=1}^{M} \sum_{n=1}^{N_m} \Delta f \log_2 \left(1 + SINR_{n,m}\right) \tag{15}$$

where, M signifies the total number of user equipment (UE) and N_m indicates the number of transmitting RRHs simultaneously for serving m^{th} UE. Signal to Interference plus Noise Ratio (SINR) of m^{th} user linked with n^{th} RRH as follows [35],

$$SINR_{n,m} = \frac{p_n h_{n,m}}{\sum_{k \neq n}^{N} p_k h_{k,m} + \sigma^2} \tag{16}$$

where, p_n is the wireless transmission power of n^{th} RRH, $h_{n,m}$ is the channel gain between n^{th} RRH and m^{th} user, and σ^2 denotes average noise power.

Now the energy efficiency denoted as η_{EE} can be written as follows,

$$\eta_{EE} = \frac{C_t}{P_g} \tag{17}$$

where, P_g is the grid PC, calculated as,

$$P_g = P_{total} - P_{solar} \tag{18}$$

According to the definition, EE is inversely related to the on grid power consumption. A lower value of on grid power consumption implies better EE and vice versa.

G. SIMULATION SETUP

The proposed network is deployed using a hexagonal grid layout of BSs equipped with omnidirectional antennas. We considered that, up to 50 users per cell and the users are randomly distributed. The system parameters, which are listed in table 3, are taken from [8] and [9].

III. RESULT AND ANALYSIS

This section compares the performance of the proposed C-RAN network model with different solar PV capacities (1 kW, 2 kW, 3 kW and 4 kW) to traditional C-RAN. The typical C-RAN configuration specifies the network as being powered solely by traditional grid power, with no integration of solar energy sources.

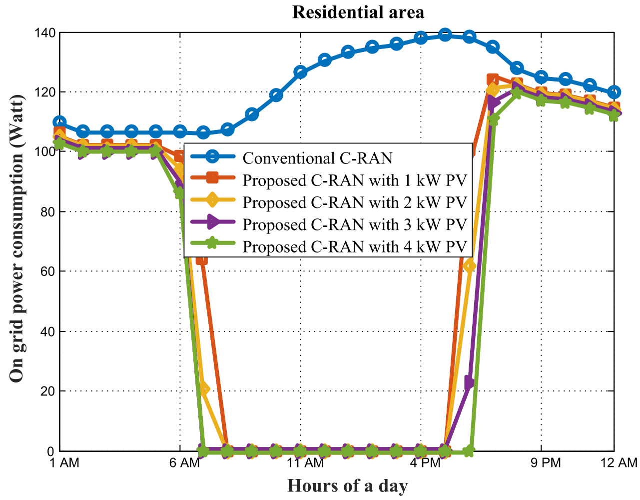

FIGURE 8. On-grid power consumption in the residential area for 20 W transmitting power.

Figures 8-11 depict on-grid power consumption for residential and office locations with varying solar capacity over the day. Until 6 AM, when there is no sunshine or there is no storage in the battery, the BBUs-RRHs are fully powered by on-grid electricity. When the sun rises, solar PV starts to yield energy, grid consumption gradually down to zero with the obtainability of solar energy generation. This can be seen that, the grid power consumption is zero for a long time (i.e., 8 AM to 6 PM for all solar panels capacity used 1 kW, 2 kW, 3 kW and 4 kW). The batteries store extra electricity during the day for later use when demand energy is less than solar energy. As can be observed, grid energy saving are greater for increased solar PV capacity, resulting in significant network performance and energy efficiency improvements. However, as shown in the figures, the observation related 4 kW solar panel conquers an improved performance. It can be stated that utilizing as much green energy as possible reduces grid use greatly. On the other hand, traditional C-RANs are disreputable for running on grid power.

Figure 12 shows the power sharing timing diagram of proposed and conventional network. As seen, up to 6 AM, a BS is completely run by on-grid supply as solar energy is unavailable during this period. After this, on-grid energy consumption gradually decreases with the increase of solar energy availability and up to around 8 AM the BS run with both solar energy and grid energy. The on-grid energy consumption becomes zero at 8 AM and between 8 AM to around 6 PM, there is adequate solar energy available for running the BS, and hence, no consumption of conventional grid energy. During this period, a BS fulfills its demand from its own solar energy storage and stores the surplus energy. The stored surplus energy is used between 6 PM to 8PM and at

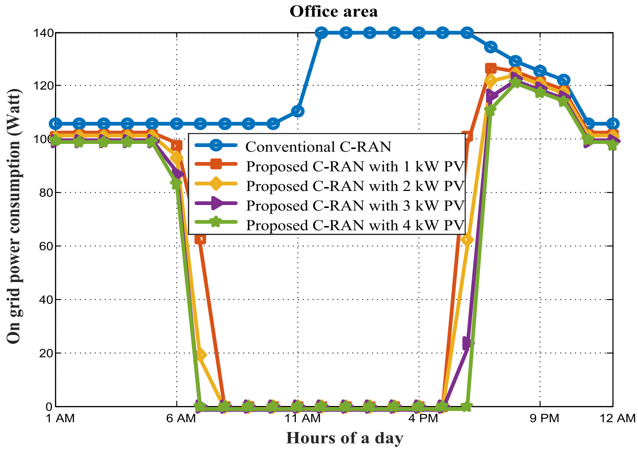

FIGURE 9. On-grid power consumption in the office area for 20 W transmitting power.

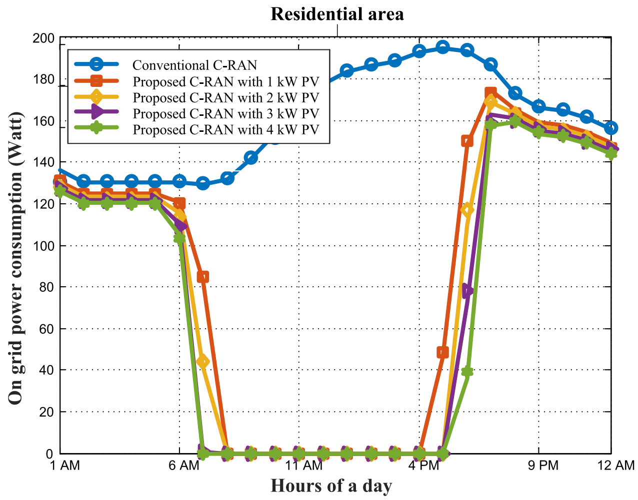

FIGURE 10. On-grid power consumption in residential area for 40 W transmitting power.

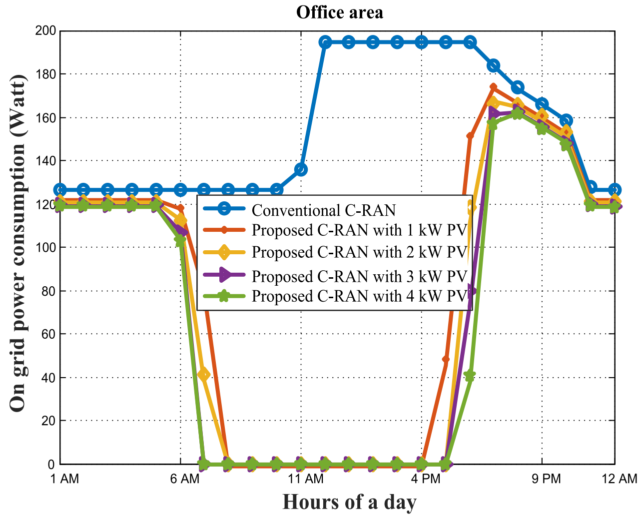

FIGURE 11. On-grid power consumption in the office area for 40 W transmitting power.

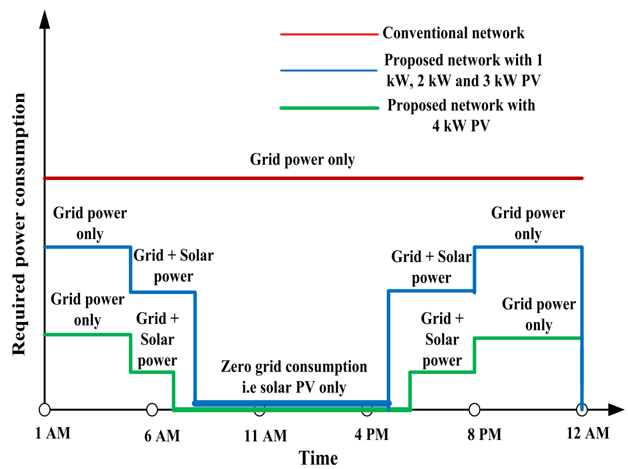

FIGURE 12. Power sharing timing diagram of the proposed and conventional network.

this period the BS run with both solar energy and grid energy. After this, up to 12 AM the BS is again run by on-grid supply only as solar energy is unavailable during this period.

The comparison of on-grid power consumption between the residential area and the office area for 20 W transmitting power is shown in Figure 13. The conventional C-RAN scheme has consumed 2939 W for the residential area and 2871 W for the office area over the day which has completely taken from grid supply. In contrast, the proposed C-RAN scheme with 1 kW, 2 kW, 3 kW and 4 kW PV has consumed grid power of 1564 W, 1473 W, 1406 W and 1355 W for the residential area while grid power consumption for office area are 1513 W, 1423 W, 1357 W and 1326 W respectively. Hence, the proposed C-RAN with 1 kW PV reduces grid power consumption by 47%, while 2 kW reduces it by 50%, while 3 kW and 4 kW reduce it by 52% and 53.8% respectively compared to the conventional C-RAN.

Figure 14 presents the on-grid power consumption comparison between the residential area and office area for 40 W transmitting power. The conventional C-RAN scheme has consumed grid power of 3862 W for residential area while 3726 W for office area over the day. On the other hand, the proposed C-RAN scheme with 1 kW, 2 kW, 3 kW and 4 kW PV has consumed grid power 2105 W, 1951 W, 1871W and 1833 W for the residential area while grid power consumption for office area is 2050 W, 1880 W, 1802 W and 1769 W respectively. Hence, proposed C-RAN with 1 kW, 2 kW, 3 kW and 4 kW PV reduces grid power consumption in the network by 45%, 49%, 51.5% and 52% compared to the conventional C-RAN.

The throughput performance of C-RAN is plotted in Figure 15 throughout the day. As seen in the Figure for traditional C-RAN and suggested C-RAN, this curve closely matches the traffic load curve graph. Furthermore, the throughput curves for both the proposed system and the

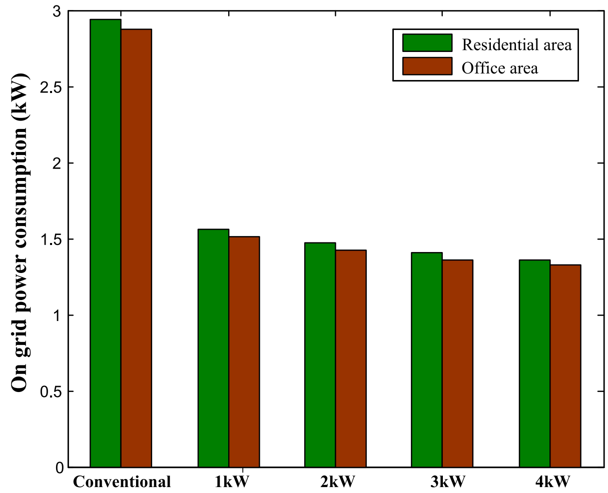

FIGURE 13. Comparison of total grid power consumption between residential & office areas for 20 W transmitting power.

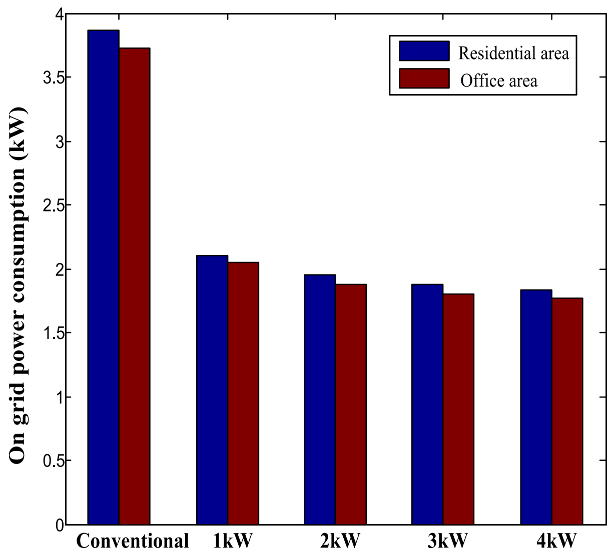

FIGURE 14. Comparison of total grid power consumption between residential & office area for 40 W transmitting power.

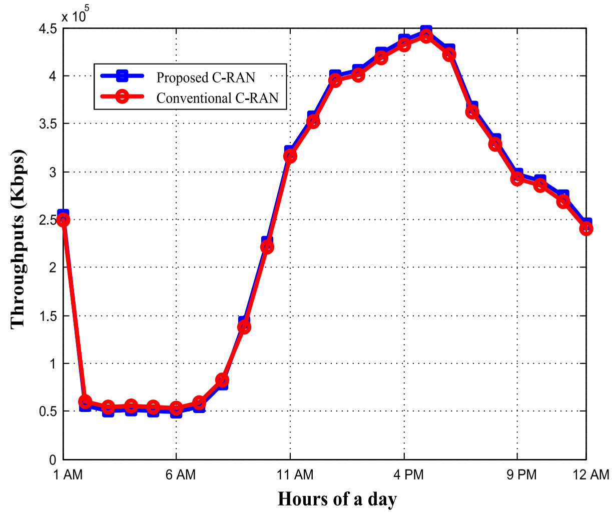

FIGURE 15. Throughput comparison between Proposed C-RAN and conventional C-RAN.

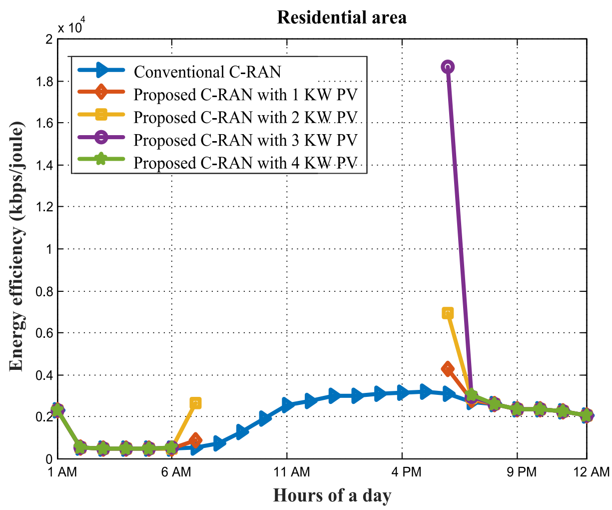

FIGURE 16. EE performance of proposed C-RAN and conventional C-RAN in the residential area for 20 W transmitting power.

traditional C-RAN overlap. This is because throughput is completely reliant on cellular system bandwidth as well as resource blocks (RB) and is unaffected by battery usage. We assume that each RB is occupied by one user and that the traffic distribution is as follows. As a consequence, the nature of RRH's power consumption has no effect on the data transfer rate.

Figures 16-19 demonstrate the EE comparison of the proposed network with traditional C-RAN for both residential and office areas over the day.

Figure 16 and Figure 17 depicts the energy efficiency of residential and office area for sending power of 20 W, while Figure 18 and Figure 19 depicts the energy efficiency of residential and office area for transmitting power of 40 W. The net on-grid power consumption is inversely proportional to the system's EE. With the sufficient solar energy generation, the EE reaches to infinity indicating that there is no on-grid energy consumption as the stored green energy at that period nullifies the need of on-grid consumption. In the Figure, break lines indicate this situation. As observed from Figures 8-11, the grid energy consumption is zero for a prolonged period of time i.e., 8 AM to 5 PM for 1 kW, 2 kW and 3 kW and 7AM to 6 PM for 4kW panel capacity. Hence, in Figures 16-19, the EE of Proposed C-RAN with 4 KW PV reaches infinity for the period of time of 7AM to 6PM and this condition is marked by break line in the Figures. As shown in the Figures 16-19, the vacant zone of the RE-based C-RAN hybrid model with 4 kW energy harvester capacities is comparably broader than the other solar PV models. As a result, the proposed solar PV network with 4 kW becomes very high compared to the other. EE curves, on the other hand, continue to descend.

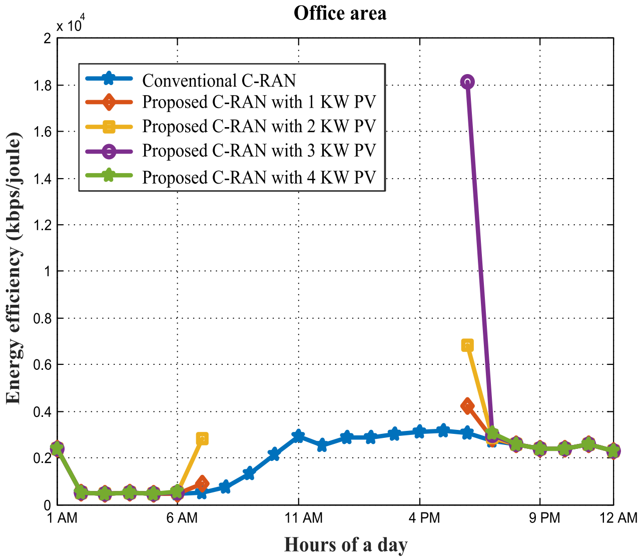

FIGURE 17. EE performance of proposed C-RAN and conventional C-RAN in the office area for 20 W transmitting power.

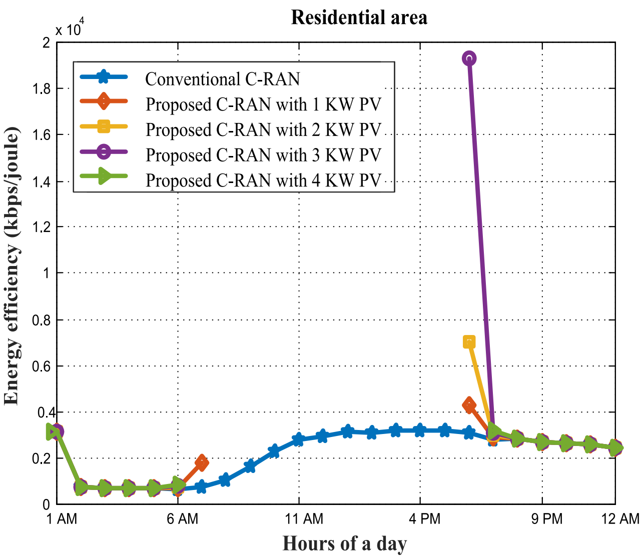

FIGURE 18. EE performance of proposed C-RAN and conventional C-RAN in residential area for 40 W transmitting power.

During the night, when the stored energy is substantially smaller, the load demand on the cellular system is much lower. Furthermore, because of the variance in energy storage capabilities, the EE gap is more noticeable at night. The EE improvement of our suggested model for various solar capacities for different geographical locations is shown in table 4. As mentioned in table 3, for 20 W transmitting power, the proposed C-RAN scheme with 1 kW, 2 kW, 3 kW and 4 kW PV has improved the EE of 50%, 67%, 80% and 91% for the residential area while EE improvement for office area are 53%, 69%, 84% and 94% respectively compared to the conventional network. On the other, the proposed C-RAN scheme with 1 kW, 2 kW, 3 kW and 4 kW PV has improved

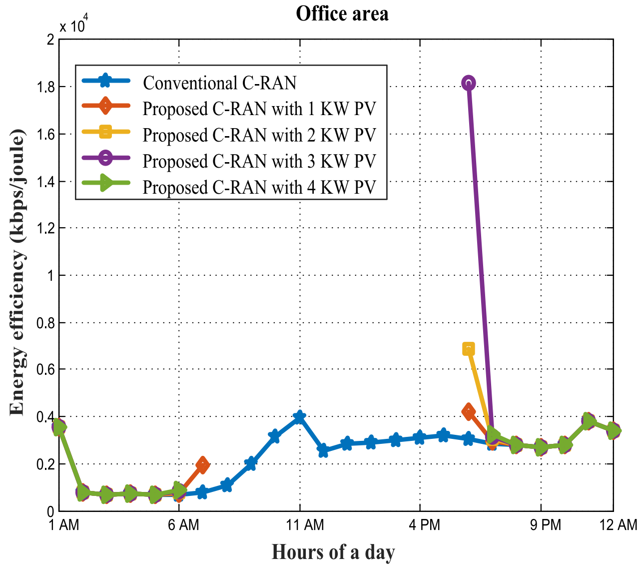

FIGURE 19. EE performance of proposed C-RAN and conventional C-RAN in office area for 40 W transmitting power.

TABLE 4. Comparison of EE improvement.

Network model	Solar PV capacity	Energy efficiency improvement (%)			
		For 20 kW transmitting power		For 40 kW transmitting power	
		Resident ial area	Office area	Resident ial area	Office area
Proposed C-RAN	1 kW PV	50%	53%	21%	26%
	2 kW PV	67%	69%	50%	52%
	3 kW PV	80%	84%	78%	79%
	4 kW PV	91%	94%	88%	90%

the EE of 21%, 50%, 78% and 88% for the residential area while the EE improvement for office area are 26%, 52%, 79% and 90% respectively for transmitting power of 40 W. Therefore, it can be concluded that, the proposed network with 4 kW solar capacity has been recognized as more energy efficient compared to the conventional C-RAN.

IV. CONCLUSION

We have suggested a new energy-efficient C-RAN architecture that uses RE to improve EE performance in a cloud-based cellular network. The BSs have been proposed to be connected to both renewable energy sources such as photovoltaic solar panels and traditional grid power to reduce the consumption from the later one. The proposed cellular network models have a great potential to reduce the total grid consumption when compared to the conventional network. Moreover, we examine EE for various solar PV capacities, intending to reduce on-grid power usage as much as possible. Furthermore, increasing solar module capacity results in a significant improvement in EE performance. Experimental results demonstrate that in comparison to conventional C-RAN, the proposed system with 4kW module capacity achieves maximum EE of 91% and 88% for residential areas and 94% and 90 % for office areas while the transmitting power are 20 W and 40 W respectively.

The scalability of the framework will be established by developing the generalized algorithms and analytical model for the network with more base station, as well as the verification of network parameter like number of users of the network. It will be the focus of future extensions of this work. Also, adding the blocking probability and delay is beyond the scope of this paper. Hence, different delays sensitive services and optimize their execution time inside the BBU pool will also be investigated in our future work.

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MST. RUBINA AKTAR received the B.Sc. degree in electrical and electronic engineering (EEE) from the Rajshahi University of Engineering and Technology (RUET), Rajshahi, Bangladesh, in 2012, and the M.Sc. degree in electrical and electronic engineering (EEE) from the Bangladesh University of Engineering and Technology, Dhaka, Bangladesh, in 2019. She is currently pursuing the Ph.D. degree in electrical and electronic engineering with RUET. From 2012 to 2018, she was a Lecturer with the Bangladesh Army University of Science and Technology, Nilphamari, Bangladesh, where she has been an Assistant Professor with the Department of Electrical and Electronics Engineering (EEE). Her research interests include energy efficient cloud radio access network (C-RAN), 5G, mobile cellular communication, HetNets, energy efficient, and cooperative techniques.

MD. SHAMIM ANOWER received the B.Sc. and M.Sc. degrees in electrical and electronic engineering (EEE) from the Rajshahi University of Engineering and Technology (RUET), Rajshahi, Bangladesh, in 2002 and 2007, respectively, and the Ph.D. degree in electrical engineering from the University of New South Wales, Australia, in 2012. He was a recipient of BOG Gold Medal for being 1st in B.Sc. degree. He is currently a Professor with the Department of Electrical and Electronics Engineering (EEE), RUET. He has published over 100 refereed publications including journal (16 Q1 ranked in Scimago) and conference papers with H-index 18, i10-index 29, and 954 citations. These covers the target sectors: Energy and Mining Technology, Quantum Information, Advanced Digital, Data Science and ICT, and Cyber Security. Scopus Ranking: 1st in RUET and 6th in Bangladesh (2015–2019 and 2015–2020). His research interests include wireless communication: security analysis, underwater acoustic signal processing: theory and applications for ICT, power system research: energy quality enhancement, planning, operation and control, photonics: theoretical design of devices for ICT, and machine learning: application in biomedical engineering.

MD. ZAHURUL ISLAM SARKAR (Member, IEEE) received the B.Sc. and M.Sc. degree in electrical and electronic engineering from the Rajshahi University of Engineering and Technology (RUET), Bangladesh, in 1996 and 2000, respectively, and the Ph.D. degree from the School of Electronics, Electrical Engineering and Computer Science, Queen's University Belfast, U.K., in 2012. He is a currently a Professor with the Department of Electrical and Electronic Engineering, RUET. His current research interests include information-theoretic security aspects of MIMO and cognitive radio channels and security in physical-layer network coding. He is a member of the IEEE Communications Society.

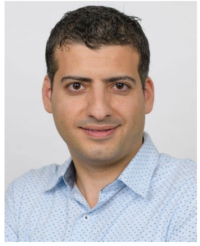
ABU SADAT MD. SAYEM received the B.Sc. (Hons.) and M.Sc. degrees in electrical and electronic engineering from the Rajshahi University of Engineering and Technology, Bangladesh, in 2011 and 2015, respectively, and the Ph.D. degree (with the Vice-Chancellor's Commendation for Academic Excellence) in electronic engineering from Macquarie University, Australia, in 2021. His current research interests include wearable antennas, flexible antennas, transparent antennas, and antennas for biomedical applications. He regularly reviews articles for top-class journals in his research field. He was a recipient of several prestigious awards and scholarships, including the Vice-Chancellor's Commendation on Ph.D. thesis, the Commonwealth Government funded International Research Training Program Scholarship to support the Ph.D. degree in Australia, the Prime Minister Gold Medal from Bangladesh, and the University Gold Medal from the Rajshahi University of Engineering and Technology.

MD. RASHEDUL ISLAM received the bachelor's degree in electrical and electronic engineering from the Bangladesh Army University of Science and Technology (BAUST), in 2022. As a student in BAUST, he has involved in many undergraduate courses, such as communication engineering, mobile cellular communication, telecommunication engineering, optical fiber communication, power systems, electrical circuit, electronic circuits, signal and systems, and digital signal processing. His research interests include 5G, mobile cellular communication, and digital communication systems.

ALLAMA IQBAL AKASH received the bachelor's degree in electrical and electronic engineering (EEE) from the Bangladesh Army University of Science and Technology (BAUST), in 2022. As a students in BAUST, he has involved in many undergraduate courses, such as communication engineering, mobile cellular communication, telecommunication engineering, optical fiber communication, power system, signal and systems, and digital signal processing. His research interests include green energy communications and renewable energy systems.

MST. RUMANA AKTER RUME received the bachelor's degree in electrical and electronic engineering (EEE) from the Bangladesh Army University of Science and Technology (BAUST), in 2022. As a student in BAUST, she has involved in many undergraduate courses, such as communication engineering, mobile cellular communication, telecommunication engineering, optical fiber communication, power systems, electrical circuit, electronic circuits, signal and systems, and digital signal processing. Her research interests include wireless communications and renewable energy.

GHOLAMHOSEIN MOLOUDIAN (Member, IEEE) received the associate's degree (Hons.) in electronics engineering from Technical and Vocational University, Yasuj, in 2008, the B.Sc. degree (Hons.) in electronics engineering from the Higher Education Center of Shiraz, in 2010, the M.Sc. degree (Hons.) in electronics engineering from Islamic Azad University (IAU) Bushehr Branch, in 2012, and the Ph.D. degree (Hons.) in electronics engineering from IAU, Arak Branch, Iran, in 2018. From January 2016 to September 2020, he worked as a Researcher and a Lecturer with the Department of Electrical Engineering, Salman Farsi University of Kazerun and IAU Kazerun Branch. He also worked with South Electrical Management Company in the field of industrial sensors and energy efficiency, from October 2020 to December 2021. He is currently working with the Wireless Sensor Network Group (Antenna/RF Team), Tyndall National Institute, University College Cork (UCC), Ireland, as a Marie Skłodowska-Curie Research Fellow and a SMART 4.0 Fellow (Smart Manufacturing CONFIRM Center). His research interests include design and analysis of RF/Microwave circuits, RF energy harvesting circuits, RFID, rectifying antenna (rectenna), smart sensors, microstrip antennas, photonic devices, smart industry 4.0, and biomedical sensors and antennas.



ALI LALBAKHSH (Senior Member, IEEE) received the B.S. and M.S. degrees in electronic and telecommunication engineering, in 2008 and 2011, respectively, and the Master of Research (H.D.) and Ph.D. degrees in electronics engineering from Macquarie University, Australia, in 2015 and 2020, respectively. He is currently an Academic Researcher (Macquarie University Research Fellowship) with Macquarie University. He has published over 120 peer-reviewed journals and conference papers. His research interests include satellite communication, high-gain antennas, evolutionary optimization methods, and passive microwave components. He received several prestigious awards, including the International Research Training Program Scholarship (iRTP) for the MRes, the International Macquarie University Research Excellence Scholarship (iMQRES) for the Ph.D. degree, the Commonwealth Scientific and Industrial Research Organization (CSIRO) grants on Astronomy and Space Exploration, the Macquarie University Postgraduate Research Fund (PGRF), and the WiMed Travel Support Grants. He was a recipient of the 2016 ICEAA-IEEE APWC Cash Prize and the Macquarie University Deputy Vice-Chancellor Commendation, in 2017. He is a Researcher in the IEEE Region Ten (Asia–Pacific) who received the Most Prestigious Best Paper Contest of the IEEE Region 10 more than once. He was awarded Third Prize, in 2016, First Prize, in 2018, and Second Prize, in 2019, from the International Competition. He is the highly commended finalist and the winner of the Excellence in Higher Degree Research Award in Science, Technology, Engineering, Mathematics and Medicine (STEMM), Macquarie University, in 2019 and 2020, respectively. In 2020, he was announced as an Outstanding Reviewer of IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION and received the Research Excellence Award of Faculty of Science and Engineering, Macquarie University. He serves as an Associate Editor for the *AEÜ—International Journal of Electronics and Communications* and *Electronics* (MDPI).