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A review on energy management issues for future 5G and beyond network

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Abstract

The much-awaited year—2021 that promises to deliver a great deal on the 5th generation (5G) wireless systems' expectations is finally here. Several solutions have been proposed to deal with the energy challenges in the evolving wireless systems, especially in 5G and beyond. These solutions have considered among other approaches, design of new network architecture based on the employment of new radio access techniques called cloud radio access networks (C-RAN), the use of heterogeneous networks approaches, the introduction of renewable energy (RE) as an alternative source of power, etc. Nonetheless, this paper's focus is ultimately on the approaches to achieve optimal energy-efficient (EE) in 5G and beyond networks based on an emerging design philosophy that promises higher overall system capacity at a low energy cost. It focuses on four key EE solutions for future wireless systems: EE resource allocation, network planning, RE, and C-RAN. It discusses various related work, research challenges and possible future work for these four areas. Moreover, the advantages and limitation of new proposed 5G and beyond RON architecture are also reviewed. It is expected that the readers of this study will understand different EE solutions to achieve an optimal EE network.

Keywords Energy management issues · Energy-efficient (EE) resource allocation · Network planning · Renewable energy · Cloud-radio access network (C-RAN)

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1 Introduction

The current demands for high data rates by mobile users are steering the reinvention of newer technologies to progress 3GPP access networks [1]. Several researchers and mobile operators are working with the 3GPP to achieve higher throughput with greater user capacity [2]. The next-generation mobile network will be stated as 5G and expected to overcome the previous generation's limitation [3, 4]. The predicted data rate for the 5G network is around 100 Gbps with a minimum of 1 ms latency and better user capacity and battery life [5, 6]. In order to achieve the acceptable quality of service (QoS), various potential solutions are in progress, such as the use of millimeter-wave (mm-wave) frequency band [7–10], massive multiple-input and multiple-output (M-MIMO) [11], Cooperative network using relay nodes (RN) [12], coordinated multipoint (CoMP) [13], wireless software defines networking (WSDN), device-to-device (D2D) communication [14], internet of things (IoT) [15, 16], ethernet passive optical network (EPON) [17], mobile ad-hoc network (MANET) [18, 19], cognitive radio [20], big data and mobile cloud computing (BDMCC) [21]. It also uses several power optimizations [22, 23], routing approaches [24–26], spectrum management [27], scheduling algorithms [28], and energy management schemes [29] in the existing technology. In recent times, energy management has become one of the major pillars in the design, implementation, and operation of wireless and cellular communication networks [30]. Unlike cellular networks operated several decades ago, which were designed to optimize specific key performance parameters such as offered capacity, delay, and throughput [30]. However, the focus has been shifted towards the emergence of EE as additional key performance indicator, owing to the development of smart devices and the massive proliferation of data- and energy-hungry applications that have continue to escalate progressively during the last decade. With these in mind, EE is thus considered a prominent figure of merit in the implementation of the next generation 5G (and beyond) wireless systems [31].

Indeed, 5G networks will provide ubiquitous internet and cellular services to cater to the more than fifty billion devices forecasted to be internet-enabled by the end of 2020 [32], including the human-type and machine-type communication systems. Indeed, to be able to provide wireless services to such an unprecedented number of intelligent nodes implies that the next generations wireless networks will inevitably incur the high cost of energy operation, and thus, we must be aware of the offered energy capacity relative to the current standards in order to be able to brace for the future demands [24]. It is doubtful that the 5G EE expectations can be realized relying on existing network architecture setups. This will undoubtedly result in a massive energy crisis and significantly raise operation cost and the issue of environmental safety. This is due to the high emission of Carbon dioxide (CO2) as we have mentioned earlier, existing systems are set up to achieve optimal capacity by merely increasing the transmit power [33]. Considering the predicted magnitude of future wireless networks, the option of scaling the transmit power in order to achieve a capacity boost will be unsustainable [34]. Meanwhile, current wireless systems still depend heavily on the traditional carbon-based energy sources, which still sustains the emphasized concerns [35–37].

To fulfill the high demands for EE and data capacity, researchers are now paying closer attention to C-RANs as a prominent candidate technology to 5G networks [38]. C-RAN architecture is a cellular system consisting of a chain of remote radio heads (RRHs) and a pool of centralized baseband processing units (BBU) (see Fig. 1). The BBU pool handles complex baseband signal processing and playing other upper layer roles, while the RRHs only perform basic functionalities related to radiofrequency (RF) such as transmission and receptions of the RF [39]. Connections are established between the RRHs and BBU pool via high-speed fronthaul channels that can either be wired or wireless. The beauty of C-RAN based on RE source is that it improves the cellular networks overall system capacity and boosts the EE [40, 41]. Ultimately, 5G based HetNet based on cloud radio network (H-C-RAN) will incorporate numerous evolutionary technologies such mm-wave, F/SBSs, BS-sleep/wake, RE, etc., to genuinely satisfies and attains the optimal EE requirement of future networks [36]. However, due to the instability of RE power sources, only low-power profile BSs such as SBSs and wireless access points (APs) can at this present time be sufficiently powered using RE in practical networks [42, 43]. The RE powered H-C-RAN architecture, where the primary network equipment draws power from distributed green energy sources connected through the smart grid is now a popular paradigm that presently is being researched by industries and academia [44]. Strategic optimization of RE cellular networks has shown that SBS can consume much less power by using the above approaches [45] with H-C-RAN architecture powered only by grid power supply can equally be EE [46].

The transition to 5G mobile communication systems is being shaped by the unprecedented demand for EE and large system capacity, fueled by the envisaged massive number of intelligent nodes that will dominate the internet arena in the near future coupled with the service complexity of the future wireless networks. The summary of this work's contribution is as follows.

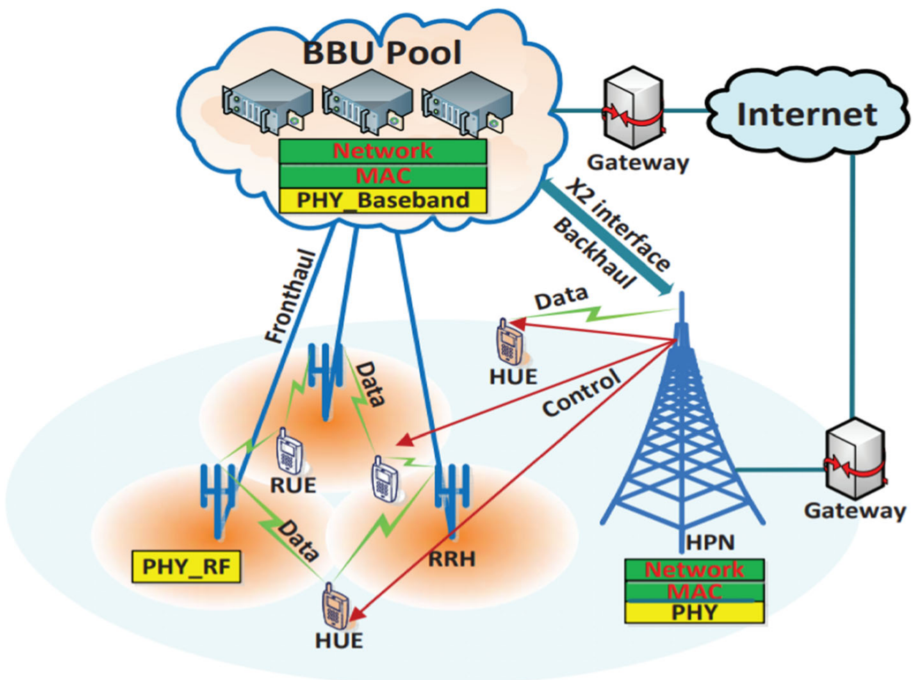


Fig. 1 5G-H-C-RAN network architecture

- This paper reviews the challenges and requirements of the next-generation wireless networks, namely, 5G and beyond, from energy management perspectives.
- This survey focuses on four critical EE solutions for future wireless systems: EE resource allocation, network planning, renewable energy, and C-RAN.
- It discusses various related work, research challenges and possible future work related to EE resource allocation, network planning, renewable energy, and C-RAN.
- It also proposes a 5G and beyond EE architecture powered by RE energy source and grid energy source while relying on key emerging complementary technologies such as F/SBS, massive MIMO, mm-waves communication, D2D communication, high speed optical fronthaul links, BS sleep/wake, H-C-RAN, and CoMP interference control scheme.

The remainder of the paper is organized as follows: In Sect. 2, the motivation of this about energy management issues in 5G has been presented. Section 3 discusses the energy-efficient resource allocation approaches, including the recent related works, summary, and future work. Section 4 gives extensive reviews of network planning, including network densification along with some recent works, and then suggests a way forward for future works. In Sect. 5, the discussion related to renewable energy is presented, followed by analyzing related works, summary and suggestions for future work. Section 6 presents a cloud-radio access network with some recent works and summary along with future work. Section 7 gives the various research challenges and proposed 5G and beyond Radio-Optical Communication Networks (RON) architecture along with its challenges and future direction. Finally, the conclusion is shown in Sect. 8. The taxonomy of this survey is presented in Fig. 2 and "Appendix" shows the list of Acronyms presents in this study.

2 Motivation

As one of the essential requirements for 5G, it is said that the energy/power consumption will decrease on the order of magnitude to be able to sustain the power requirements for the envisaged upcoming huge mobile data transactions [47]. To achieve this with the existing wireless systems structure is extremely challenging if not impossible [48, 49]. Moreover, presently, every wireless network operator worldwide focuses mainly on minimizing CO2 emissions by reducing the rate of power transmission of the BSs. Fortunately, recent years have seen a dramatic surge in research interests in the area of EE wireless communications, which have been reported in a growing body of publications and in recent conferences, described as "green communications" [50]. The European Union Seventh Framework Program (EU FP7) EARTH aims to decrease the energy consumption and electromagnetic emission of the BSs by 50% based on the current framework. Apart from the issue of environmental safety, it is also not economical, from an operation's point of view, to continuously increase the energy consumption of communication

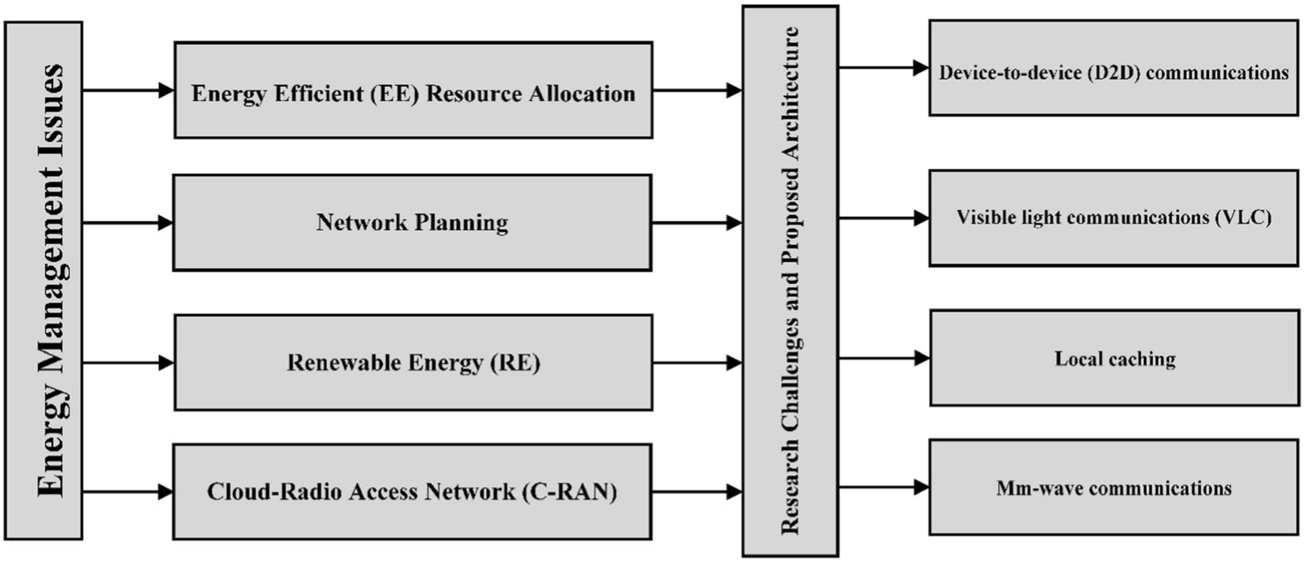


Fig. 2 Taxonomy of the survey

systems. Moreover, due to the fast-growing network density, the largest portion of the energy is being consumed by the access network, i.e., at the edge [51]. To achieve a meaningful power reduction in the future wireless networks, researchers are recently paying considerable attention to the following areas (1) Energy Efficient (EE) Resource location, (2) Network planning, (3) Renewable Energy, and (4) Cloud-Radio Access Network. Each of these will be discussed in greater detail in the subsequent sections under the respective mentioned topic. All the emerging technologies and techniques used for resolving the energy management issue are well discussed in this paper's subsequent sections. To the best of the author's knowledge, no such comprehensive study is available in the literature focusing on these four-research areas concerning energy management issues. The detailed discussion about numerous approaches can help the reader to understand the available enabling technologies in a manner that allows them to work seamlessly together to achieve the expected results for the EE 5G and beyond network.

3 Energy efficient (EE) resource allocation

With the advent of various smart devices and the wide range of high-speed business applications, mobile data traffic is growing exponentially [52]. Efficient energy resource allocation models for future wireless systems have been in increasing demand, and to meet the EE and data capacity requirements of the future wireless networks, many more EE resource allocation schemes with different energy management mechanisms have continued to emerge [53]. In the same vein, various network design scenarios, such as ones incorporating radio over fiber and C-RANs, enabled with low-power nodes (LPNs) such as SBSs, ground remote radio heads (GRRH) and other emerging 5G technologies (as shown in Fig. 3) [54]. They are being proposed and studied to understand how energy resource allocation in future 5G HetNets could be efficiently managed and economically achieved. Cloud computing, a subset of software-defined wireless communication networks, can offer high data rates at a low energy cost [55].

3.1 Related work

Efficient energy resource allocation models have been widely researched in the literature [56]. It demonstrates that a large amount of energy can be saved by slightly reducing the data rates and designing energy-aware coordinated beamforming for HetNets [57]. In [58, 59], the authors experimented with EE models that use energy harvested from visible light, also known as solar energy, to power a wireless system. The authors in [60] studied EE resource allocation that uses a harvesting transmitter based on the thermoelectric energy source, which was found to possess the benefits of long life. However, the major drawback of the thermoelectric energy devices is that they have a low energy conversion efficiency. The resource allocation mechanism based on green EH systems faces numerous challenges because of the randomness in the energy packets collected from the surrounding environment. In [61], the authors considered the uplink of the hybrid HetNet overlaid by macrocell BSs, and then proposes a two-layer game-theoretic framework to achieve EE and increase the usage of network resources. The proposed outer layer allows each small cell access point (SCAP) to

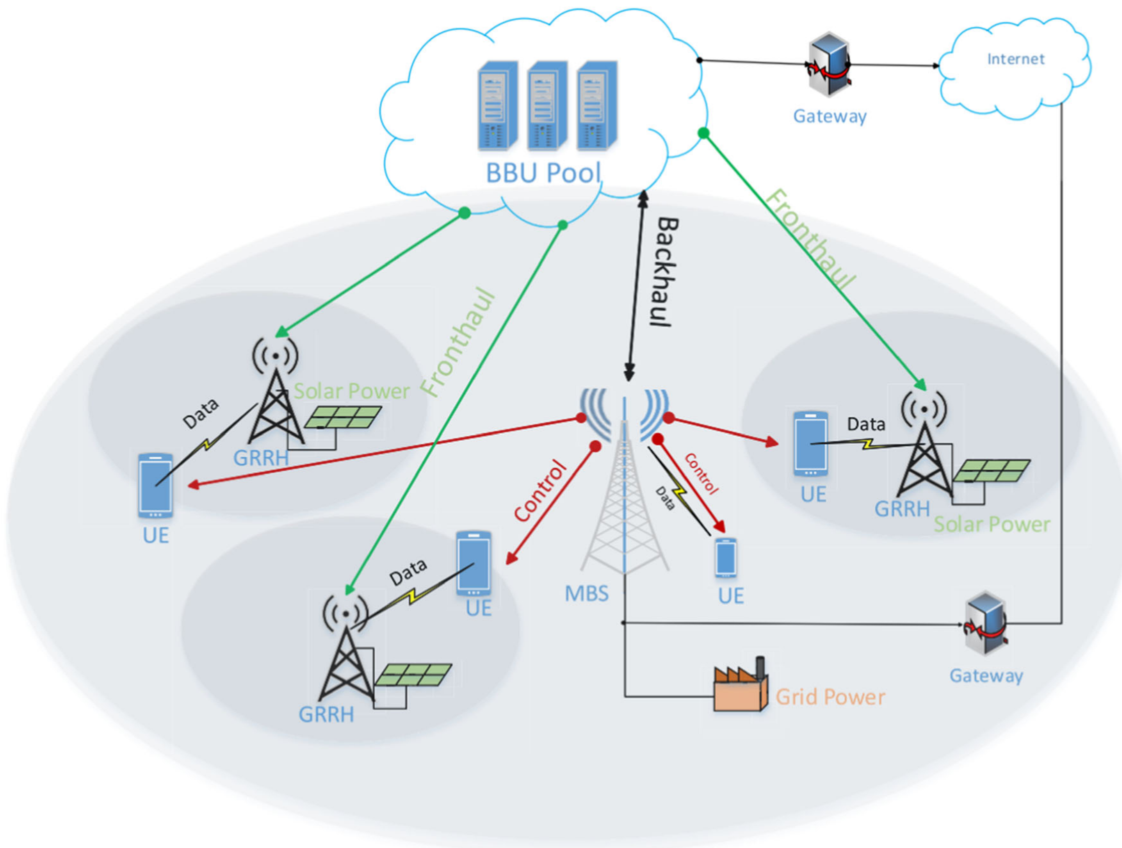


Fig. 3 EE resource allocation in 5G network architecture

achieve a maximum data rate usage by opting for the frequency band ranging between sub-6 GHz and frequency in the mm-wave bands. An optimal transmission structure that aims to increase the overall capacity of time division multiple access systems by load-balancing the spectrum resource among the RRHs and MBSs was proposed in [62]. It achieves optimal resource utilization on attributes such as energy distribution, fairness, waiting time, processing time and throughput among the servers, BSs and machines [63]. In [64], a power allocation algorithm is known as water-filling factors aided search for EE optimization of Orthogonal frequency division multiplexing (OFDM)-based cognitive RAN. It was proposed and experimented with in the areas of total power constraint, interference power constraint, and capacity constraint [65].

To obtain a maximum EE with minimum sum-rate requirements, less interference, and transmit power constraints, a joint spectrum and power allocation algorithm based on bisection search and fast barrier methods were proposed in [66, 67]. Although the minimum sum-rate requirement and minimum rate requirement for all users and each user were considered in [66] and [67], they do not consider scheduling since they assumed the investigated problems were feasible. In [68], some network elements' EE was exploited to the maximum, using channel optimization and power allocation based on the stable matching and Hungarian algorithm. Authors of [69] formulated the EE resource allocation problem as a Stackelberg game and applied a gradient-based iteration algorithm to solve it. However, both [68] and [69] did not consider the network elements' QoS. In [70], an auction-based EE resource allocation tradeoff technique for vehicular HetNets was proposed. Similarly, in [71] and [72], EE-RA joint scheme integrated with D2D communications was studied using cooperative relaying and EH setup. A similar method was also proposed in [55] for H-C-RAN networks.

Furthermore, the authors of [73] studied RA policies that optimize the proportional fairness (PF) efficiency in mm-wave massive MIMO. This scheme focuses only on SE and user fairness but ignores the EE. Joint SE-EE user relation was investigated in [74] for small cell based mm-wave networks. On the other hand, the authors of [70] considered distributed antenna system (DAS) and compared cochannel resource allocation schemes for EE communication. In [71], the authors studied a single-cell HetNet having one macro and one picocell for efficient resource allocation such that the EE is maximized by proposing an iterative resource allocation algorithm. However, the same authors did not consider multicellular network for the evaluation.

4 Summary

EE resource utilization is one of the bedrock of future wireless communication systems. To achieve any meaningful power consumption minimization and interference reduction in the future generation of wireless networks, an evolution of wireless network architectures that integrates new EE resource allocation management. Like, SBSs based on BSs on–off strategy, new EE physical layer design for 5G, network virtualization such as cloud computing and C-RAN, and supports for advanced signal processing and networking technologies, are seen as the dominant network architecture of the 5G cellular networks [75]. This section of the paper has thoroughly reviewed several mechanisms and enumerated possible schemes to achieve power-efficient resource allocation goals. It supports equitable energy-spectrum resource sharing among network elements (servers, SBSs, RRHs, MBSs, etc.) in future 5G wireless networks. Table 1 presents a summary of additional related work focusing on energy resource allocations.

4.1 Future work for energy-efficient (EE) resource allocation

The idea of energy transfer over the network seems impressive. Future works should be directed towards efficient EH techniques that are capable of both extracting and transferring renewable energies, including energy from the radio signal, from one BS to another to save the day in the event of partial traffic. The process of extracting energy from the radio signals enables the recycling and utilization of energy, otherwise would have been wasted. This way, interfering signals become a natural source of electromagnetic-based energy to power the future wireless networks.

5 Network planning

In recent years, wireless networks have become more ubiquitous and have been integrated into our everyday life, thereby promoting the need to rework the existing systems. Network planning remains one of the effectively-researched areas in recent times, driven by the fact that existing network architectures require a serious upgrade on the energy and spectrum efficiencies to the upcoming 5G and beyond wireless networks [86]. Current wireless network architectures were traditionally designed with coverage and mobility in mind while not consider EE [87]. To minimize the amount of consumed energy, novel network architectures that consider the spectrum efficiency (SE) and the EE are highly on demand. Cloud computing, an emerging technology with the ability to offer high data rates at a lower energy cost, has formed an integral part of next-generation network planning, design, and implementation. In order to realize the maximum EE, several potential technologies have been proposed for the planning, deployment, and operation of 5G networks [88].

5.1 Network densification

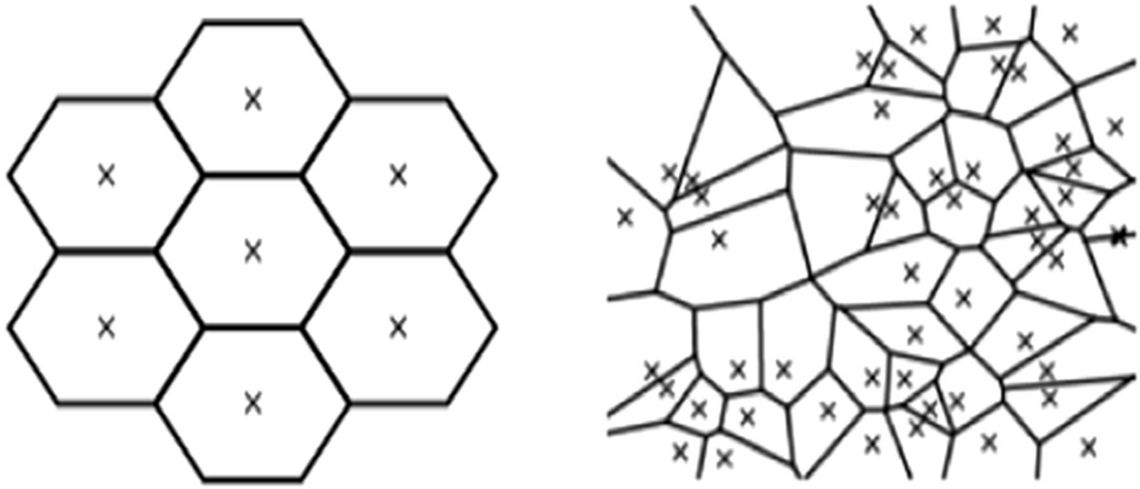
Network densification aims to contain many devices that will be internet-enabled by increasing the sheer number of deployed infrastructure equipment. Two main kinds of network densification are presently gaining more recognition and are considered strong candidates for the deployment of 5G networks.

(1) Dense HetNets: Unlike existing network designs that uniformly sectorize a macro-cell into a few numbers of sectors all covered by a single MBS, dense HetNet involves a large-scale deployment of low power profile infrastructure nodes per unit of the area [89]. A very large number of varying sizes of BSs ranging from MBSs to FBSs or femtocells and relay nodes are deployed opportunistically and activated based on demand, thus leading to a haphazardly shaped network arrangement such as that shown in Fig. 4(a) and (b) [84].

Certainly, low-powered SBSs, which are subsets of the larger HetNet, can be deployed in hot traffic zones to boost capacity and help circumvent most bottleneck design issues associated with traditional MBS deployments [90]. Although the dense deployment of SCNs can help address the traffic and energy demands of the future wireless networks, effective but low complex techniques that monitor each BS's operation states and traffic conditions dynamically place them into sleep or awake mode [91]. It makes it relevant for random cell locations, especially with dynamically changing user distributions and varying spatial and traffic loads so that more energy could be saved, provided the QoS of users such as access delay is not compromised. This approach will result in the low cost of energy operation for the overall network and significant energy savings for delay-tolerant network traffic [92, 93]. Active BSs both consume power and increase interference in the communication environment. Ultimately, a strategic EE network planning that incorporates the scheme for monitoring and controlling the number of active BSs [94] by integrating the design of adaptive BS wake/sleep schemes for energy savings is expected to be widely adopted in future wireless networks [95, 96]. Furthermore, the deployment of 5G networks will involve installing new BSs equipment that supports a variety of services since 5G

Table 1 Additional related work for EE resource allocation

Issue	Methodologies	Advantages	Limitations/future work	References
EE resource allocation within timesharing Multiuser systems based on hybrid EH transmitter	Modification of conventional nonconvex objective function through fractional programming approach also uses the lagrange dual decomposition technique	Boost energy coherency appertaining to timesharing multiuser systems to solve the convex problem	Preclude hybrid EH system is needed	[76]
Energy-aware resources allocation with green cloud environment	Ant colony algorithm technique to determine suitable virtual services for operational energy minimization	It restricts the dynamic resources and maximizes resource utilization	When the input package size exceeds the current utilized resource, the un-utilized resource will be switched in the next stage	[77]
Energy adaptive with EE downlink resource allocation	A distributed resource allocation problem is modeled as a noncooperative game, and each player optimizes its EE with the help of RRH	Reduces the mobile device energy consumption	Limited to downlink transmission only	[78]
C-RAN EE resource allocation	Hybrid structure algorithm via joint channel selection and power allocation that exploit C-RAN, RRHs and centralized baseband unit pool	Increased QoS performance along with boost EE for cellular and D2D users	Techniques carry out and limited to a centralized Baseband unit pool	[79]
Cloud datacenter EE virtual machine allocation	EE virtual machine allocation method with an interior search algorithm (ISA) that lower data center energy consumption	maximize resource utilization and mitigate data center energy consumption	An advance virtual machine concept is needed when users facing highly mobility	[80]
EE upstream data transmission with joint resource allocation for in OFDMA-PONS, through software-based optical network units (ONU) reconfiguration	OFDMA-PON to minimize the differences in frame formats and multiplexing	upper bound energy-saving and mitigate the time-unit power consumption by ONU reconfiguration	Restricted to upstream data transmission only	[81]
Weighted sum-rate maximization online resource allocation in EH downlink MIMO	High-dimensional stochastic dynamic programming (SDP) method based on mixed binary and Continuous variables and non-concave objective function	Mitigate computational burden and the proposed method gives substantial performance gains compared to other conventional models	Higher MCS needed for real-time users' application	[82]
Resource allocation with the signal-to-interference-plus-noise ratio (SINR) based for simultaneous information and power transfer in a wireless multiuser, single-hop network	Weight perturbation Lyapunov method for scheduled data optimization for schedule data transmission and energy splitting factor	Improved performance in terms of less data queue and lower battery size	Delay factor not included in this scheme	[83]
EE resource allocation scheme based on physical-layer network coding (PNC) with two-way amplification in OFDM bidirectional transmission	The closed-form optimization power allocation scheme is proposed, which is based on Joint subcarriers and power allocation of optimal EE power allocation (OE-PA) method	A significant increase in energy saving	Restricted relay power and interference system	[84]
EE resource allocation in D2D under relay network	It proposed the Iterative combinatorial auction (ICA) game algorithm based on bidder competing for resources consumed by the users	Lower power consumption as compared to conventional techniques	Limited to one channel for D2D and cellular users	[85]



(a) Macrocell network

(b) Network densification

Fig. 4 a Macrocell network. b Network densification

is projected to become a prevailing General Purpose Technology that will generate trillions of dollars in the global economy [97]. In order to reduce management overhead, the HetNet based small BSs will be equipped with new Radio Access Technologies (RATs) [2] enabled with the softwarization of network functions [98] that increase the network capacity and operational EE of the evolving wireless systems [99].

(2) Massive MIMO If the goal of network densification is to increase the number of deployed SBS infrastructures, the purpose of massive MIMO becomes to increase the number of deployed antenna elements. Traditional massive MIMO consists of arrays with only a few antenna elements fed by bulky and expensive hardware. Massive MIMO for next-generation wireless systems comprises arrays with hundreds of small antenna elements provided by low-cost amplifiers and circuitry. The research interest in massive MIMO technology was prompted by work done in [100], which observed how large antenna arrays could average out multi-user interference due to the law of large numbers. However, the challenges faced by massive MIMO systems are; first, deploying large-scale antenna elements shows that enormous MIMO is an extensive system, usually too complicated for a microscopic analysis [101].

5.2 Related work

Recently, there has been a growing body of literature that deal with different issues in the designs of EE SCN, suggesting that network energy resources can be significantly maximized by implementing EE sleep/wake techniques. This makes a BS into a sleep mode based on short-term service demand with flexible access strategies for end-users. Thus, a tangible amount of energy can be saved in a network designed to meet the peak-hour traffic by (periodically) turning off the BSs. It happens when they are not serving any active users or only, during periods of low traffic while transferring responsibility to the MBS that overlaid the muted SBS [102]. This is by no small means part of key design factors to be taken into consideration during the network planning and design phase. In some cases, the geographical area is split into multiple grids, according to the authors of [103]. Several SBSs plenty enough to serve all users at peak traffic hours selected for each grid area. During idle periods, a subset of the selected SBSs is placed in an active mode while the remaining BSs are turned into sleep mode. This approach achieves up to 53% energy consumption minimization in densely deployed areas and up to 23% in sparsely deployed areas. Authors of [104] have employed the reinforcement learning mechanism to dynamically place under-loaded SBSs into sleep mode while concurrently satisfying the QoS requirements. The problem associated with controlling numerous sets of APs where each AP serves one user equipment (UE) so that the most significant number of UEs experience the maximum service quality [105]. Each UE is assumed to have access to multiple cells and can switch between multiple paths during its service period. The preference for the number of accessible cells over near-by cells is an open research paradigm that is yet to be investigated appropriately.

The authors in [106] consider power control and cell cooperation EE and cell zooming algorithm that provides EE to cellular network operation by comparing the channel models. EE decode-and-forward (DF) relay-assisted network with EH and power-grid BS scheme based on sleep/wake technique is investigated in [107, 108]. Considerable research efforts have been made in the area of delay tolerant networks in the literature [109]. The EE SCNs have not been explored in detail to ascertain the actual energy-saving performance of a given network and the consequence of latency for certain delay-sensitive users when specific small cells are placed into sleep mode. For the implementation of EE-SCNS, the authors of [110] focus on cross-layer optimization of 5G and beyond RONs where network planning and execution are based on centralized C-RAN infrastructures. It establishes the optical backhaul connectivity between RRHs and centralized BBUs pools located in the cloud to facilitate the realization of radio signal processing functions and provide high data rate and low latency transmission required by 5G services in the access network.

6 Summary

Of course, a good measure of energy can be saved by deploying SBSs based on the adaptive sleep/wake techniques that adequately considers users' QoS experiences. In this section, several other complementary technologies and methods to facilitate the design, deployment and realization of 5G networks have been discussed, including network densification [111]. The EMF constraints may impact 5G planning, and taking this factor into account in the early stage of planning is a step in the right direction as this directly affects the operators' CAPEX and 5G capacity to support many upcoming state-of-the-art services [112]. Table 2 shows other related work done on network planning and deployment in 5G communication networks.

6.1 Future work for network planning

The huge amount of data activities initiated by various intelligent devices and other high-speed business applications calls for a holistic redesign of existing network architectures. The future network design aims to develop a unique form of an architectural model that proves EE and effectively handles such bandwidth-intensive applications in future wireless networks. Based on this paper's extensive review, we advocate using HetNets, built around optical fiber technology, grid and renewable-energy-powered SBSs, mm-wave and C-RAN technologies. The MBS is connected with the BBU pool via Backhaul, whereas various GRRH are associated with the BBU pool via Fronthaul. Not only will this minimize network power consumption, but it will also enhance the network capacity of connected devices. Meanwhile, enormous works still need to be done to tackle interference issues associated with H-C-RAN networks caused by inter and intra tier signals interfering with one another. Thus, further work on the design of EE 5G-based HetNets should focus more on the above-highlighted challenges.

7 Renewable energy (RE)

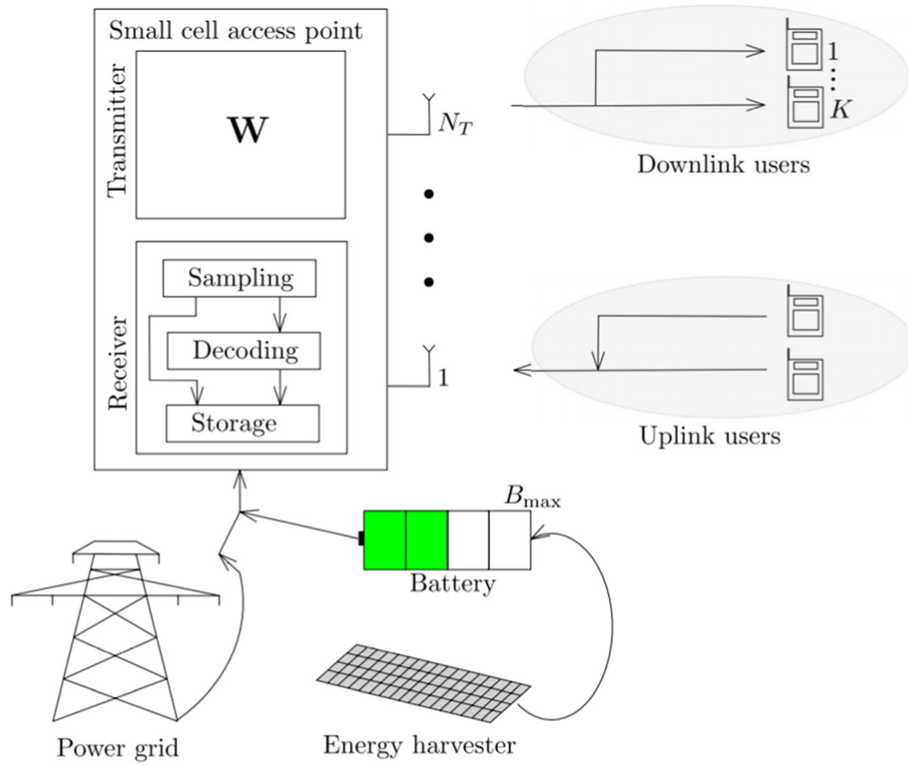
The massive increase in the population of SCNs is expected to solve the bulk of issues related to EE, high capacity and enhanced reliability in the future 5G wireless networks. However, these benefits seem to diminish when considering the high energy consumption cost at those numerous BSs (MBSs and SBSs alike), which translates to more CO2 emissions into the human ecosystem [123]. Cellular operators are now paying closer attention to develop RE technologies to power the BSs in addition to the grid power source. In this new arrangement, the grid energy source will play backup support to ensure uninterrupted service to the users if eventually, the RE source becomes unavailable or insufficient [124]. Another huge leap in energy-saving is the recent development of BSs that RE sources can power through solar systems [125]. This type of technology is needed not only in developed countries but urgently and badly needed in developing countries where reliable and ubiquitous power grids are mostly absent. It is also more interesting as it allows "drop and play" rather than "plug and play" for SBSs and SCNs deployment in the presence of wireless backhaul. However, due to the fluctuating nature of RE source, the energy harvested by BSs may not be enough to support their load conditions. As a result, the transmit power of the BSs for the emerging wireless networks needs to be further redesigned.

Power control in mm-wave networks using grid-RE cooperation mechanism can be a great way to solve the energy imbalances as well as minimize the energy waste by solely powering each BS through RE source. This is done by backing up the same BS by an alternative grid power source, and the harvested energy can also be stored up and transferred from one BS to another (see Figs. 5, 6). This way, each BS needs to determine whether the energy should be stored in the battery or transferred to another BS at any given time slot [126]. Researchers have tried several power optimization approaches, including formulating power control as a stochastic optimization problem, to maximize the time average network utilization efficiency while keeping the network stable. An online algorithm called dynamic energy-aware power allocation (DEPA) is based on the Lyapunov optimization approach. Technically speaking, power control schemes with energy cooperation can achieve a higher network sum rate and reduce the delay and the required battery capacity [127].

Table 2 Additional related work for network planning

Issue	Methodologies	Advantages	Limitations/future work	References
EE association with a control algorithm	BS sleeping and wakeup scheme between BS and the resource reservation overhead of its neighboring BS	Minimizes the energy consumptions	Limited user association algorithm network resources between the wake-up and hibernation of the BS	[113]
Power control and cell cooperation EE scheme for cellular network	Cell zooming algorithm that provides EE to the operating cellular network by comparing the channel models	Increased EE	Need to increase receiver sensitivity with random BS locations also	[114]
Sleep mode joint optimization to decrease the dense small cell networks energy consumption while maintaining user's rate requirements	Cooperative sleep and power allocation (CSPA) scheme to optimize active subframes of SBSs and power allocation	Increased EE with maximum power allocation	Small cells with cognitive radio capability parameters can be considered for future	[115]
EE decode-and-forward (DF) relay-assisted network with EH and power-grid BS scheme	Power control and sleep mode management based on EE resource allocation (EERA) scheme	Substantial increase of energy-saving approach provide theoretical insight of EH relay system	Relay transmission due to the inadequacy of harvested energy	[116]
OFDMA EE Resource Allocation based on terminals in frequency-selective channels	Terminal sleep model in combination with resource allocation method for homogeneous and HetNets to reduce terminal energy consumption	Boost the EE FDMA-based wireless multicast systems and mitigate the total time for terminals received mode	Limited to terminal focused resource allocation	[117]
Separation architecture for control plane and data plane for whole network EE	Separation architecture of probabilistic data BSs (DBS) sleeping mechanism	It boosted typical daily traffic profile EE and offer a tradeoff between energy-saving and network capacity	Computational complexity increases	[118]
Green wireless networks radio resource management	Dynamic radio allocation schemes that switch resources instantaneous change for system load along with semi-static radio allocation schemes that activate and deactivates resources that depend on the traffic load	Reduced energy consumption through sleep mode	More advanced algorithm is needed for real-time user's application	[119]
Combination of BS sleeping strategy, resource allocation, and RE procurement scheme to reduce carbon emissions	Optimization of BS sleeping strategy with bi-velocity discrete particle swarm optimization (BVDPSO) algorithm—Lagrange dual-domain approach to enhance the power	Boost the profits of cellular operators with carbon emissions reduction and improves the tradeoff between the system throughput and energy consumption	Disregard inter-cell interference to allocate the radio resources for each cell independently	[120]
BS Sleeping (BSS) CoMP based system resource allocation	Optimization of BSS by simplified CoMP resource allocation and α-fair user scheduling approach	Significant trade-offs of energy, coverage, and rate	Further investigation needed for cost, energy, and backhaul requirement for the CoMP enabled BSS system	[121]
Sleep-mode BS resource partitioning and load adaptation strategies based on two-tier heterogeneous cellular networks (HCN)	User association scheme to mitigate SINR degradation due to user's severe inter-tier interference for users close to tier boundaries	Minimize total energy of two-tier HCN—Decrease network energy consumption	Limited to macro and small-cell BSs sleep mode	[122]

Fig. 5 Grid-RE cooperation mechanism



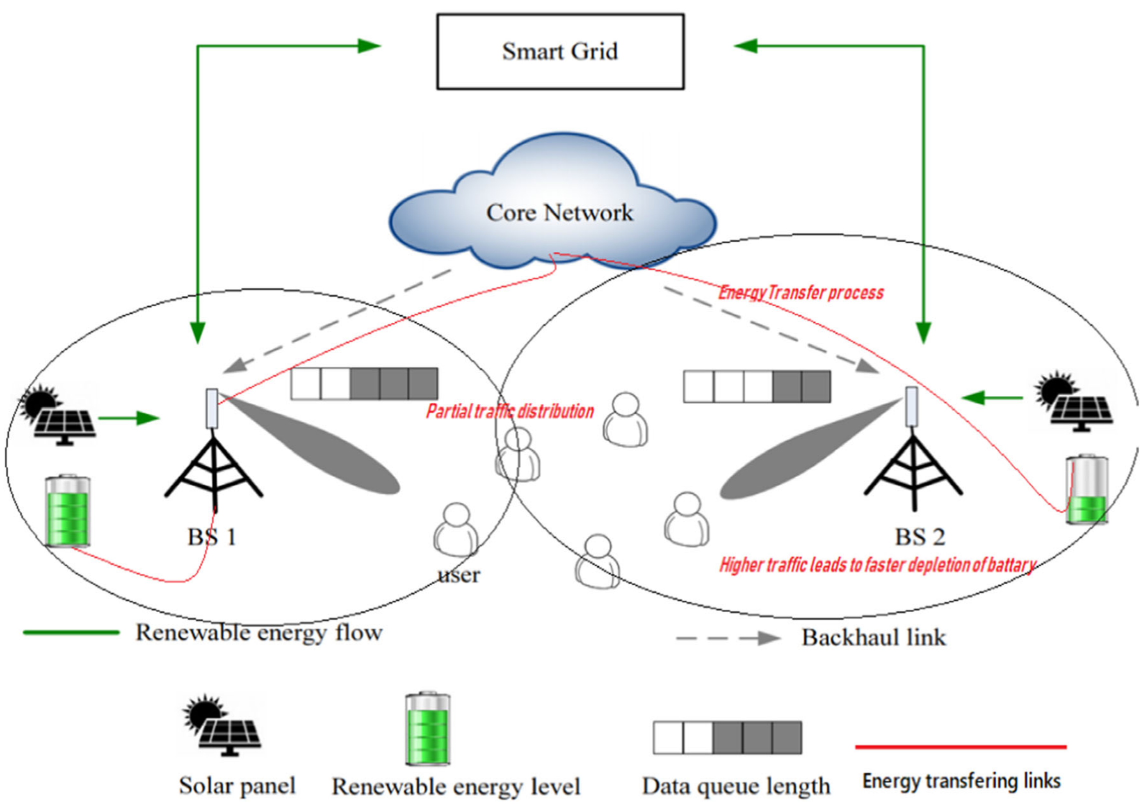


Fig. 6 RE powered network which demonstrates the concept of energy transfer from one BS to another and shows the relation between traffic load and energy consumption

7.1 Related work

The necessity to develop and implement communication systems powered solely by REsources, also known as green communication, has elicited numerous research efforts from various groups and industrial assemblies worldwide [128, 129]. The shift on 5G technology will most likely spur a disproportionate paradigm shift on the invention of innovative techniques for network deployment. It integrates renewable and grid energy optimization, efficient resource allocation, and smart BSs programmed for efficient sleep/wake control to achieve super EE optimization in the emerging wireless networks.

Numerous studies have focused on improving the network EE by way of minimizing the cost of system operation through the transmit power minimization of the BSs powered by grid energy source and applying the concept of traffic shaping based on green energy management [130–132]. Authors in [133] investigated the feasibility of integrating hybrid energy sources in the proposed scheme to produce multi-cell green cooperation. In [134], an optimization problem for minimizing the BS transmit power over the network is presented. The proposed scheme focused on enhancing transmission reliability, information security, and EH to reach an optimal solution. In [135–137] optimized user association and green power allocation algorithms are adopted to minimize the grid energy consumption, and in [138], an efficient resource allocation based on the hybrid power system was introduced to minimize grid energy consumption, considering battery leakage constraint. Optimal grid EE and achievable QoS were gained using Lyapunov power control and BS assignment algorithm [139], and a game theory strategy has experimented for cooperative energy to reduce grid energy consumption in SCN [140]. In [141], the BS muting technique is used to achieve optimal performance in grid energy consumption as well as maximize capacity in a cellular system that uses EH mechanism. Adaptive user association was applied to achieve maximum system capacity in EH aided system and optimal EE was achieved by power-sharing control among the BSs in a HetNet using hybrid energy sources.

Moreover, in [142], a technique known as "first harvest-then-transmit" was used to attain optimal EE on a user level and maximize the system's throughput of the harvested energy. Simultaneous wireless information and power transfer (SWIPT) are experimented in [143] with cloud radio access cellular networks that gathered energy from a six frequency-band system that in allowed devices to harvest sufficient energy from RF, thus improving the total EE throughput of the cloud-based radio access cellular network. In [144] massive MIMO technique was applied to EH scheme based on a heuristic algorithm to achieve optimal EE and the capacity boost in SCNs. However, the bulk of these works center on transmission policies enhancement, capacity and power allocations optimization for end-users [134–141], and front-haul links [135–139]. Earlier works which focused more on the point-to-point link [140–142], and broadcast link [145, 146], had used a hybridization of renewable and non-RE sources combined to build an energy structure that supplies the required amount of energy for access network communication from the renewable source, while the non-RE source serves as a backup to the RE source to maintain users acceptable QoS in the event the renewable source becomes insufficient. The idea of creating hybrid energy sources sounds rewarding since it ensures that access BSs will provide guaranteed and uninterruptible connectivity.

8 Summary

RE is now more than ever, a hot topic in the power management of wireless communication systems due to the conflict between the booming traffic demand and the limited energy resources. In this section of the paper, an exhaustive list of algorithms for harvesting and harnessing the RE that can be extracted from readily available resources such as wind, sun, hydro dams, and RF for future cellular networks has been outlined [147, 148]. Operating a wireless communication system through RE can be indeed a highly appreciated alternative as it presents a green communication paradigm. Despite the enormous economic and environmental benefits, RE sources still faced the challenges of its usage—on the transceiver strategies' design. The transceiver strategies of existing renewable EH systems must be redesigned and adapted for the intermittent nature that characterizes RE resources. Table 3 shows other related work done on the green/renewable/grid energy planning and deployment in 5G communication networks.

8.1 Future work and recommendations for renewable energy

The idea of extracting green energy from readily available RE sources such as wind, sun, hydro dams, and RF presents cellular network operators with a unique opportunity to properly manage the power crisis issues. RE technologies are particularly more beneficial to those in countries with no advanced or dependable electrical grids. Before considering the option of RE solution, feasibility studies must be done to identify those technologies capable of generating the amount of energy sufficiently enough to power the BSs. Moreover, network operators' operational and

Table 3 Additional related work for renewable energy

Issue	Methodologies	Advantages	Limitations/future work	References
Two-tier HetNet C-RAN where macrocells connected to the conventional power grid and RRH are powered by renewable energy	Lagrange dual decomposition method is used to formulate a mixed integer programming problem i.e., NP-hard	Help to reduce the energy consumption from the main power grid station	More advanced algorithm is needed when the number of users is varying very frequently in the cell	[149]
EE user association and power allocation scheme for HetNet based C-RAN, which is power by both power grid and RE source	A hybrid-fitness function evolutionary algorithm is proposed for solving the non-convex mixed binary and integer programming problem	It can give power saving of up to 26.1 and 12.6% of the energy	Delay factor not included in this scheme	[150]
The power control scheme for an mm-wave cellular network with RE resources	A stochastic optimization problem that increases the time average network utility based on Lyapunov optimization technique	Higher network sum rate and less delay	More advanced power allocation scheme is required which should consider data queue length	[151]
Cost optimal planning for renewable realistic time-varying distributed network	The optimization algorithm is proposed, which is based on an iterative procedure combining Gauss–Seidel decomposition with the competitive game formulation	Better peak average ratio	More scheduling algorithm is needed for enhancing the scalability of the network	[152]
Energy allocation and cooperation of EE scheme for renewable multi-tier network	It proposed convex optimization parameterization and an extended convex-concave procedure to maximize the network efficiency	Better sum-rate and improve energy consumption	Both hybrid power source and energy cooperation need to improve	[153]
Energy management between the main power grid and multiple renewable power suppliers (RPSs)	The game-theoretic approach is used to manage the traffic latency of backhaul and cordite independent RPSs on the RE storage level	The better tradeoff between the energy-saving and cost of QoS	Computational complexity increases	[154]
Reduces the on-grid energy consumption for HetNets	Low complexity optimal offline algorithm is proposed, which considered battery capacity and traffic information	The adaptive on-grid energy consumption is reducing while using renewable energy	The factor for Energy transfer among the BSs is not considered in this scheme	[155]
Reducing the average grid power while maintaining the QoS	A two-stage dynamic programming algorithm is proposed, which helps to optimize the BS on–off states and active resource block allocation strategy	Less computational complexity as compared to optimal joint BSs strategy	Delay factor can be included in future	[156]
Resource allocation for Hybrid Energy network to increase optimal energy consumption	A low complexity suboptimal online resource allocation (SORA) algorithm is proposed	Low computational complexity while achieving the optimal battery capacity	Limited to download OFDMA network	[157]
Efficient use of energy source among users to solve the quadratic programming problem	A low complexity distributed algorithm which is based on average consensus and without relying on the centralized decision	Deliver better energy consumption cost	Future algorithm should include pricing function, storage devices, and users load	[158]

economic costs should also be carefully considered by network operators before deciding on a suitable implementation. Likewise, the site where the RE facilities such as the RE-powered BSs will be situated should be considered to prevent any unforeseeable disruption caused by dirt, dust, tree debris, moss, sap, water spots, and mold, etc. EE cellular networks based on green energy remain a broad research topic facing several issues that are yet to be adequately addressed; some of these issues have been discussing in this paper. Cellular network operators must shift toward green-powered network alternatives to reduce operational expenditures and minimize environmental damage.

9 Cloud-radio access network (C-RAN)

Nowadays, Cloud technologies and services are becoming very popular due to the extended usage advantages they offer, which include accessibility, high speed, security, storage, processing speed, etc. [159, 160]. However, cloud resources' prominent drawback centers around the energy cost for operating specific cloud communication components and cloud-based network devices. The examples are servers and storage devices as well as power required for cooling the IT loads, all of which contribute to high operational cost and increased emission of carbon into the human territory. Thus, cloud service providers and cloud operators need to look towards green cloud technology as an alternative to the existing cloud schemes to introduce a green cloud environment that will cut down on the operational cost of energy and reduce the environmental impact of carbon emission [161]. RAN based on cloud technology, also referred to as C-RAN, is designed to handle the issue of high capacity demands for future wireless networks since the cloud is inherently structured to offer high SE and minimize access delay for delay-sensitive applications. The EH architecture for C-RAN will be different from that of the traditional cellular networks [162]. The C-RAN architecture split the functions of conventional BS into BBUs and distributed RRHs [163]. The BBU pools are deployed in the centralized cloud data center for controlling, baseband signal processing, and data processing. In contrast, the RRHs are connected to the BBU pools through high-speed backhaul links. The RRHs perform RF-related functions such as decompressing the received signals from the BBUs and transmitting them to UEs. From the EE point of view, the dense deployment of RRHs equates to an avenue for more energy consumption, which translates to high emissions of carbon dioxide. To address this, it is imperative to develop EH schemes that equip the RRHs with the ability to autonomously harvest RE from solar and wind energy sources [164]. Thus, RRHs powered by RE will be highly instrumental in realizing the much-desired environment-friendly green cellular communications. To sufficiently support delay-intolerant applications, C-RAN will require highly optimized resource management algorithms that are both efficient and scalable considering the large number of RRHs and BBUs that a potential C-RAN (see Fig. 7). Furthermore, the performance of C-RAN network can be optimized by integrating a particular emerging complementary concept, as explained below.

(1) Centralized baseband processing Energy economization is one of the key features that make C-RAN an attractive architecture for future wireless network deployment. C-RAN will save more energy since it centralizes the backend baseband processing units in the cloud, which is more EE [165], especially if the recent progress in green data centers are exploited efficiently [166].

(2) Small cells approach One of the significant options [167] and an effective technique to achieve substantial energy saving in a C-RAN setting is via adopting a small cell deployment option. Likewise, the mm-wave will be of significant importance for offloading data locally in C-RAN networks given the unprecedented amount of available bandwidths in the higher frequency space, also stated as mm-wave [168]. For example, the VLC uses only the mm-wave frequency bands for data communication. The energy consumption per unit bulb for transmitting high-density data in the VLC paradigm is much less than that consumed by its RF-based counterpart for sharing the same amount of data [169].

(3) H-C-RAN The concept of HetNet, has been well-known and has been practiced within the wireless network industry over the last couple of decades because it has remained a viable option for maximizing the throughput and the efficiency of various network resources, including energy. H-C-RAN-based SCNs that encompass SBSs, mm-wave, VLC, etc., remain a good architecture to provide a massive SE and zero access delay and high throughput at a low cost of energy in the future wireless networks. H-C-RAN based mm-wave architecture that was suggested for 5G cellular networks in [170] is a C-RAN concept built on the architecture of the HetNet using SCNs and mm-wave frequency bands to offload data locally in the access network [171]. In this type of network architecture, SCNs are created within macrocells to allow mm-wave application within the small cells using the VLC and other mm-wave oriented RATs to connect to edge user devices with enhanced QoS experiences [172].

(4) Interference issue One of the well-known challenges in HetNet remains the issue of severe interference [173]. This is merely owing to the densely deployed BSs that characterized the HetNet networks. H-C-RANs, which have emerged as promising architecture in recent years improve the performance of MBSs using SBSs and cloud-based signal processing mechanisms. It is also known as BBU pools interconnected via high-speed optical fibers, which had inherited the interference challenge from the HetNet [174]. Fortunately, the same set of schemes, such as inter-cell interference coordination (ICIC) and coordinated multiple points (CoMP) transmission and reception that were used to handle the interference issues in HetNet, can also be applied in H-C-RAN paradigm [175]. H-C-RANs scenario enables easy implementation of the ICIC [176]. The ICIC rates are very high among other key schemes employed for improving the interference performance of H-C-RANs [177]. However, the application of these great interference controlling schemes in modern cellular and wireless networks is still limited due to their heavy reliance

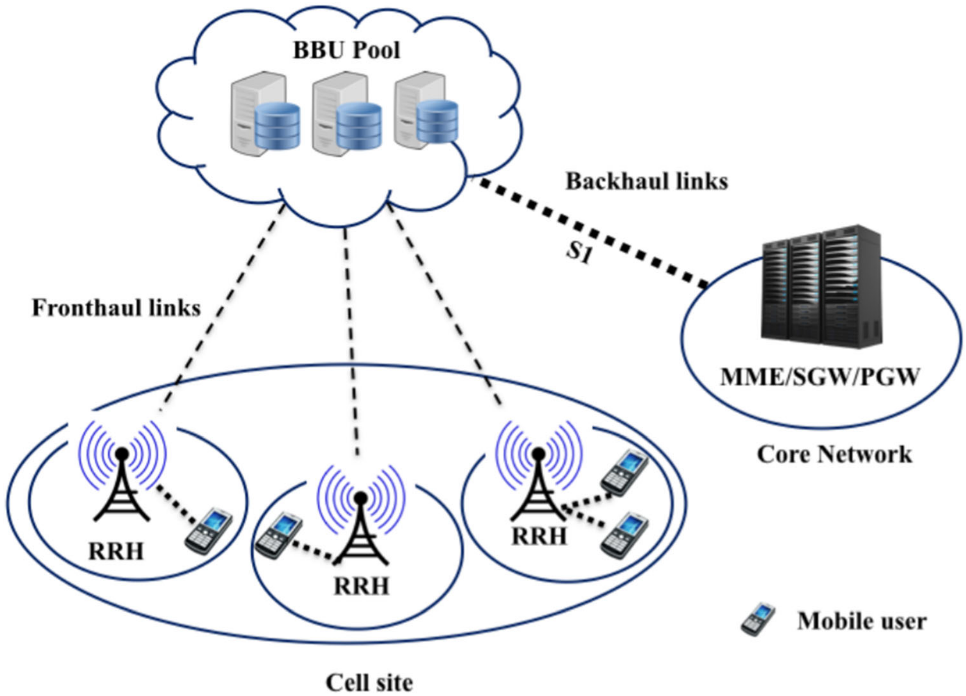


Fig. 7 RRHs—BBUs distributed H-C-RAN radio network

on the backhaul connections and cellular networks' computation resources [178].

9.1 Related work

Most existing C-RAN works focus mainly on the spectrum performance optimization, while fewer mentions have been made of the EE allocation mechanisms [179–182]. In [179] the EE for the wireless downlink in H-C-RAN was investigated and analyzed. In [180], Zhang et al. studied the resource allocation scheme in green H-C-RAN with a hybrid energy source. Authors of [181] dissected the EE guaranteed trade-off between offered capacity and delay in H-C-RAN [182]. In [183], a design of EE resource allocation algorithm based on joint channel selection and power allocation for H-C-RAN was proposed. However, the above scheme did not consider the randomness in the EH processes but only focused on optimal EE, and as a result, they cannot be applied in C-RAN based EH setting, abbreviated as EH-C-RAN. Although the delay is an essential parameter for measuring the QoS in wireless networks, the proposed solutions in [184] did not provide a guaranteed delay bound to evaluate the QoS requirements. To address this, the authors in [185] proposed a resource allocation scheme with dynamic EH policies based on stochastic channel state to provide a guaranteed delay bound for delay-aware applications and services. In [186], the authors also studied guaranteed EE problems with throughput and delayed tradeoff in a noninterference C-RAN network. It is based on an integrated Lyapunov optimization structure, then an enhanced downlink transmission CoMP technique for C-RANs with optimal fronthaul channels for delay-aware traffic was proposed. In [187], delay-sensitive cooperative beamforming management for delay-aware services with restricted fronthaul data transmission in C-RANs was proposed. In [188], the authors considered a data decision-based transmission technique that considers the delay-awareness and data health history of sensor devices in opportunistic systems. Authors of [189] and [190] proposed a dynamic power and sub-band allocations scheme to achieve optimal Pareto power-delay tradeoff in the OFDMA system. Also, in [191], a theoretical structure was proposed to evaluate the tradeoff between power and delay in an unstable OFDMA system with a time-varying channel state information transmitter (CSIT). As a matter of fact, these kinds of solutions do not satisfy the delay-sensitive application's requirements in future C-RAN networks.

On the other hand, energy resource optimization is now one of the most important performance metrics of the H-C-RANs networks. Currently, it introduces a new paradigm in the energy management of wireless communication systems due to the sharp increase in the CO2 release and high operation cost of energy of wireless networks [192]. The power allocation technique to address EE and SE's tradeoff in the downlink of end-users devices was studied in [193] using a DAS having proportional rate limits. In [194], the authors consider multi-dimensional resource optimization that jointly encompasses power allocation, beamforming optimization, and resource block assignment further to investigate EE and SE's tradeoff in H-C-RAN networks. The EE-SE tradeoff for D2D communications was also studied in relay-assisted cellular systems [186–188]. However, many kinds of literature mentioned in the above studies mainly focused on full-buffered theories and are typically based on snapshot models that do not consider the stochastic and time-changing natures of traffic arrival in the formulations of their problems. Thus, optimization becomes only achievable in the physical layer performance metrics such as SE and EE, whereas the resulting control scheme can only be adapted to channel state information (CSI) [195].

10 Summary

C-RANs have been massively favored by academia and industries alike as a robust setup fit enough to deliver on the key performance requirements, namely, offered capacity, EE, and delay bound for future wireless networks. Indeed, H-C-RAN is a promising architecture most likely to be sustained for future wireless systems [196]. However, the advantages of H-C-RANs are still being impeded by high interference factors and this must be addressed adequately before the potentials of H-C-RANs will be fully unleashed. H-C-RAN is often discussed as a cost-effective architecture that can restrain interference, increase network throughput and enhance cooperative processing gains in future 5G HetNet [197]. Other enabling technologies such as heterogeneity in C-RAN networks, C-RAN network planning, and interference control in H-C-RAN using ICIC and CoMP schemes were also discussed in this section. The complementary techniques mentioned above can ultimately help H-C-RAN to achieve the main goals. Significantly, the number of physically deployed BSs can be reduced in C-RAN configuration as a result of BBU aggregation in the cloud, which implies a much lower cost of operation. Below is Table 4, which shows a summary of additional review to the related work done in the area of C-RAN and H-C-RAN.

10.1 Future work for cloud-radio access network (C-RAN)

C-RAN deployment faces multiple levels of challenges which range from (i) installation of BBUs to effectively utilize the processing resource, (ii) establishing proper connections between the BBU and RRH interfaces using high-speed fronthaul links, and (iii) setting up an optimal mechanism for centralized control of the propagation of signals. In addition, C-RAN performance still suffers a huge drawback as a result of the use of fronthaul links that have limited capacity and BBUs with limited processing power. To achieve C-RAN full potentials of techniques, future research should concentrate on schemes that aim to address the challenges mentioned above. Particularly, techniques that target to optimize the network throughput and reduce scheduling complexity in C-RAN networks should be further explored by any interested group. Future work should thus be directed at developing fronthaul-sensitive resource allocation schemes that will achieve optimum EE by signal compression/quantization, beamforming techniques, and includes on/off switching at the RRHs [208–210].

11 Research challenges and proposed architecture

Various EE resource allocation schemes, including those equipped with the ability to extract RE from energy sources working on various EH mechanisms and the grid energy source working in conjunction with different network designs. It also focuses on incorporating RON, C-RANs, and a host of other 5G complementary technologies in a heterogeneous manner, which have been extensively reviewed in this paper. Even though many energy management techniques discussed in this issue have been said to possess the capacity to significantly support the overall energy requirements of the future wireless systems, adopting these wide ranges of new use cases requires flexibility. Moreover, the impact of these new technologies on EE for 5G operation is yet to be precisely ascertained and quantified. New energy consumption models that consider the energy consumption that is associated with the uplink and downlink transmissions in the network are required. To this effect, the research forums and industrial organizations wishing to contribute to the future development and improvement of the EE and SE for 5G systems.

Recently, user communication devices are being furnished with multiple radio RATs – e.g., cellular, Bluetooth, WiFi, so they can easily connect to any available connection technologies (e.g., as is always the case in indoor scenarios) [211]. This simplifies the cellular traffic offloading process and makes it easy for additional cellular resources to be provided to users unable to offload their traffic, eventually making network energy efficient. Various EE approaches are stated in the literature, which has critical research challenges that need attention from the research community.

11.1 Device-to-device (D2D) communications

While user devices that are co-located do not directly establish communication between or among themselves in conventional networks. D2D communication refers to a

Table 4 Additional related work for C-RAN

Issue	Methodologies	Advantages	Limitations/future work	References
Resource allocation in C-RAN based HetNets	Two problems are solved (1) the computation task can be offloaded or not, (2) reducing the latency of the computation task. These can be solved by proposed a computation location selection and resource allocation (CCSRA) algorithm	Optical resources allocation with low computation task exaction delay	Number of cloud center are comprised	[198]
Optimal resource allocation in EH C-RAN network for delay-sensitive applications	The Lyapunov stochastic EH technique and virtual queues considered data dropping, UE request scheduling, channel allocation, and energy management	Better performance in terms of Close-to-optimal UE utility, reduce delay and bounded data buffer	With advanced resource allocation scheme which includes battery leakage and hybrid energy-related techniques	[199]
Energy consumption for C-RAN	Two resource allocation has been resolved (1) bandwidth power allocation (BPA) (2) Baseband unit energy-aware resource allocation (BBU-EARA)	Proposed algorithm delivers better results as compared to Best Fit Decreasing (BFD) an RRH-Clustering (RC)	Real-time operating system and virtualization can be done in future	[200]
For centralized and decentralized Resource allocation approaches for 5G HetNets bases C-RAN	An EE algorithm using online learning to mitigate interference among RRHs and BSs	Higher data rates for users with better QOS, spectral efficiency and lower BER	Computational complexity increases	[201]
Sustainable resource allocation for C-RAN powered by hybrid energy supplies	A net gain-optimal resource allocation (GRA) algorithm to maximize the gain while maintaining the sustainability of batteries and stabilizing the data bugger for three problems (1) data requesting (2) hybrid energy management (3) channel/power allocation	Better delay and net gain performance of proposed GRA algorithm as compared to conventional schemes	Interference and delay-sensitive service should be included in the future in the algorithm	[202]
EE algorithm for Power consumption due to traffic admission control, resource allocation, user association and power allocation in HetNets based C-RAN	The Lyapunov optimization technique is used for stochastic optimization which is based on the continuity relaxation of binary variables and the Lagrange dual decomposition method	The better throughput-delay trade-off with improved queue stability and power consumption	A delay guarantee algorithm is required for real-time traffic application	[203]
Enhance machine learning scheme for EE resource allocation for 5G HetNets C-RAN	The user's priority-based RA allocation and compact state representation-based learning methodology scheme is proposed to reduce interference and to maximize the user's QoS	Better spectral efficiency as well as increases the convergence speed as compared to conventional online learning schemes	Highly accurate channel state information (CSI) is needed	[204]
Mobile edge computer architecture is proposed for multi-layer C-RAN	A cooperative communication and computation resource allocation (3C-RA) is proposed, which is based on proportional fairness approach	Deliver low-latency computing and communication service with higher network throughput	It doesn't consider the sophisticated UE to mobile edge cloud	[205]
Joint user association and resource allocation for HetNets based C-RAN	The proposed solution consisted of three steps (1) RRH activation was done by using Greedy algorithm (2) users-RRH pairing was done on behalf of CSI (3) dual decomposition technique is used for resource allocation	Better EE gains as compared to baseline schemes	More comprehensive resource allocation scheme is needed, which includes microcell and RRH users	[206]
				[207]

setup where several co-located devices or devices that are in close communication range can directly communicate using a designated cellular frequency and at the prompt of the BS [212]. The power control underlaid D2D approach can be resolved using machine learning approaches [213, 214]. Moreover, D2D schemes will positively impact the system EE given the fact that a direct transmission between nearby devices requires a much lower transmit power than what is necessary for communication via a BS that can be far off from the user devices. Some more powerful offloading techniques are required to allow the release of network resources at the BS to support other users with proper energy management.

11.2 Visible light communications (VLC)

VLC, also known as optical wireless communication (OWC) or LiFi, is a technology that is designed for indoor communication services in the evolving wireless systems. While this technology is typically short-range, it has a very high EE performance and huge available bandwidths; thus, it can support huge data rates [215]. The use of the LiFi frequency for data communication is ultimately accomplished through low-cost and available off-the-shelf light-emitting diodes (LEDs) technique. Therefore, some advanced approaches are needed to especially for indoor communication.

11.3 Local caching

Ideally, wireless networks have unstable traffic loads. During periods of light traffic, the redundant capacity can be leveraged by the network to download and keep in the BS's cache important network contents that many users for easy retrieval frequently need. Thus, the scheme is named "local caching". Of course, this technique comes with a trade-off between storage capacity at the BS and network throughput [216]. This implies that the load on the backhaul link reduces inversely proportionally with the increase in content caching; thus, the strategy can potentially boost the EE of the core network by opting not to transmit the same content multiple times to different users. Local caching is an emerging EE offloading scheme that is still unfolding and is currently attracting widespread interest among wireless systems researchers [217].

11.4 Mm-wave communications

The use of communication spectrum above 20 GHz, also called mm-wave, as described in this section as a unique approach to performing EE traffic offloading from the mm-wave spectrum band of below 60 GHz cellular frequencies used for short-distance (from 10 to 200 m) communications in highly congested areas [218]. There are requirements for evolving wireless technologies to take advantage of the massively unutilized mm-wave spectrum to meet the projected data rate demands for future mobile traffic [219]. However, the IEEE 802.15.3c, IEEE 802.11ad (Wi-Gig), Wireless-HD, and ECMA-387 standards, are available range of mm-wave-based solutions which are already represented in IEEE, with more to follow suit in the coming years. Some machine learning approaches can also be adopted to resolve various mmWave communication scenarios, creating an EE network [220, 221].

11.5 Proposed 5G and beyond RON architecture

5G and beyond RON is a unique network design scenario for 5G and beyond (as referred as 6G) that focuses mainly on RONs based on cross-layer optimization. What is unique about a 5G network based on RON architecture (5G and beyond RON) is that the design of a 5G and beyond RON network includes a centralized C-RAN access network with optical backhaul connectivity between RRHs and centralized baseband units (BBUs) [222]. The RON architecture can bring great openings in terms of traffic offload/load balancing, refining link reliability, provisioning of hyper-speed data rate, multi-tier networks, enhancing of spectral utilization, provision for smooth handover, line-of-sight (LOS)/non-line-of-sight (NLOS) communication support, omnidirectional/directional communication support, and downlink (DL)/uplink (UL) support through different networks. This renders a 5G RON highly efficient in providing a very high data rate with low latency communication over the wireless and optical network – via densely deployed RRH antennas operating within a higher spectrum range with plug-and-play support for advanced radio communication technologies such as massive MIMO andbeamforming, at very low energy cost [223, 224].

See Fig. 8 for an example of a 5G and beyond RON network, where RH is radio header and CO is the cloud operating (CO) network device that is installed together. Designing and operating a pervasive 5G and beyond RON that spans different domains requires multi-layered architecture, namely, optical radio and packet layers. Such an architecture requires enough computational capacity and dedicated cross-layer optimization systems that consider the signal qualities of the optical fronthaul radio links of the entire network performance, including user QoS requirements. The process of selecting cell sites for 5G and beyond RON BSs placement has to abide by the standardized downlink electromagnetic fields (EMF) regulatory limits that govern the 5G network planning and deployment [225]. This EMF regulation stipulates the acceptable limits on EMF exposures for current mobile networks. Those are some of the key concerns for operators wishing

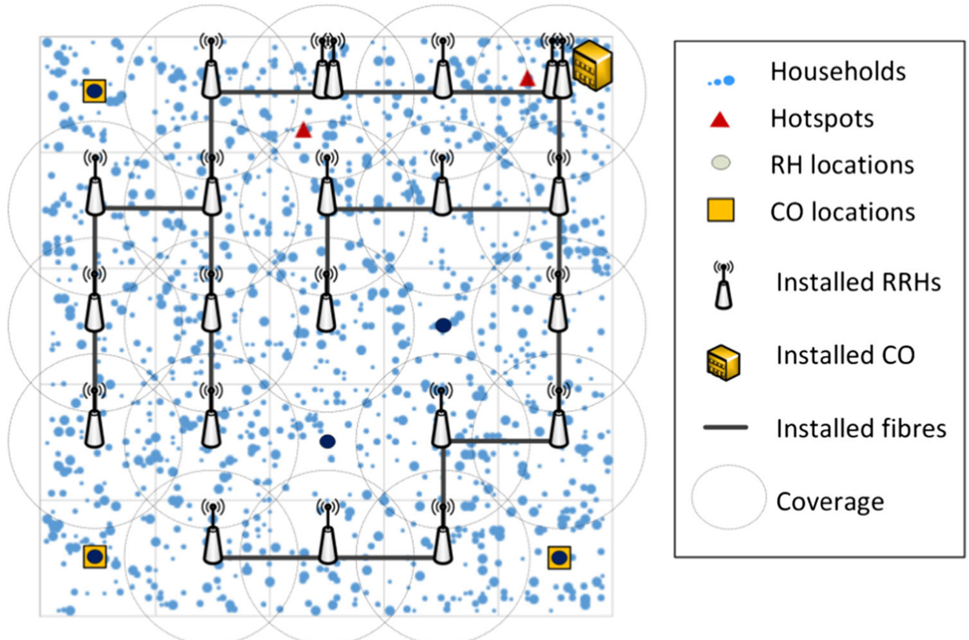


Fig. 8 5G and beyond RON architecture

to upgrade to the 5G and beyond RON mobile network, and it remains yet an open issue till date that has been largely deliberated upon in the recent International Telecommunication Union (ITU) seminars.

Below are some challenges and future directions in order to design 5G and beyond RON.

Network selection An effective network selection technique is essential in the RON network. The network selection criteria are different in RON compared to existing RF based networks because of various sub-networks. Hence, existing network selection technique should be modified to increase the overall capacity and network throughput.

Heterogeneous receiver type Both the receivers for two different networks in RON should be active simultaneously. The characteristics of RF-based receivers and optical-based receivers are different. Hence, this is a challenging task for the hybrid network to design such transmitters and design to maximize the transmission rate.

Handover Handover is an important issue in RON. Appropriate handover decision criteria and algorithms are still open research issues that can reduce the handover and consider the energy efficiency scheme to optimize the battery power of the communication device.

High-capacity backhaul network Another critical concern for RON is to provide a load balancing facility. Hence, a huge amount of overall data throughput in the access network can be increased with minimum end-to-end transmission delay. To support this data throughput, a very high capacity backhaul network is essential that is still an open research issue.

12 Conclusion

Future wireless communication networks will be mostly decentralized and characterized by small cell deployments ranging from 10 to 100 m of radius/cell. Recent studies have shown that BSs account for about 65% to 70% of total network power, implying that future wireless networks will consume way more energy than we presently experience. This is because SCN means a large-scale deployment of BSs everywhere to provide better coverage. This phenomenon makes EE arrangements such a critical issue in the implementation of future wireless networks. This study has provided an overview of several emerging technologies that can be applied to improve 5G cellular networks' EE performance. As we have pointed out in the survey, future wireless networks will comprise various enabling and emerging technologies [24, 226]. However, the biggest challenge remains on integrating the available enabling technologies to allow them to work seamlessly together to achieve the expected results. Some of the open research problems have been outlined and discussed, especially those related to EE resource allocation, network planning, renewable energy, C-RAN, testing, and measurement of new 5G system use cases. Finally, future research on 5G systems should focus on the research challenges highlighted in this paper.

Appendix: List of acronyms

Abbreviation	Meaning	Abbreviation	Meaning
AP	Access point	SCAP	Small cell access point
BBUs	Baseband units	SCNs	Small-cell networks
BS	Base stations	SE	Spectrum efficiency
DAS	Distributed antenna system	CO2	Carbon dioxide
DEPA	Dynamic energy-aware power allocation	C-RAN	Cloud radio access networks
EE	Energy efficiency	CSIT	Channel state information transmitter
EE-SCNS	Energy efficient small-cell networks	PON	Passive optical network
EMF	Electromagnetic fields	SWIPT	Simultaneous wireless information and power transfer
EH	Energy harvesting	SCNs	Small-cell networks
MBS	Macro base stations	SBSs	Small base stations
EU FP7	European Union Seventh Framework Program	UE	User equipment
H-C-RANs	HetNet based on cloud radio network	MIMO	Multiple-input and multiple-output
HetNet	Heterogeneous network	OFDM	Orthogonal frequency division multiplexing access
RA	Resource allocation	OWC	Optical wireless communication
RAN	Radio access network	PF	Proportional fairness
RATs	Radio access technologies	QoS	Quality of service
RF	Radio frequency	SWIPT	Simultaneous wireless information and power transfer
RON	Radio-optical communication networks	VLC	Visible light communications
RRHs	Remote Radio Heads	RE	Renewable Energy
SBS	Small Base Stations	CO	Cloud Operating

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Declaration

Conflict of interest The authors declare no conflict of interest exists for this work.

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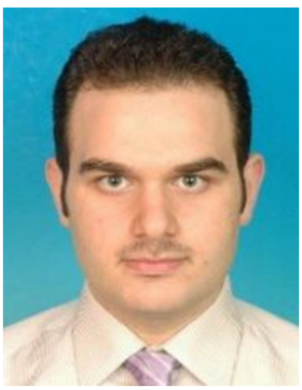

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