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How to Meet Increased Capacities by Future Green 5G Networks: A Survey

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ABSTRACT The mass and widespread adoption of connected mobile devices have brought about enormous social changes with significant economic, cultural, and technological impacts on a society that is becoming increasingly connected. Therefore, energy efficiency in future mobile generations is becoming increasingly significant for cellular network operators. To realize future green networks based on energy efficient architecture that meets the holistic requirements in terms of capacity, this paper presents an overview of the principal driving factors triggered by the next mobile generation, 5G, to fulfill the needed requirements. A detailed discussion of the various advantages and disadvantages of each of these techniques is performed to contribute to understanding how the green radio architecture for future mobile networks can be designed and what challenges may oppose this realization.

INDEX TERMS Energy efficiency, spectrum efficiency, cognitive radio, D2D, heterogeneous networks, massive MIMO.

I. INTRODUCTION

Under the "Internet of everything" principle, where everyone and everything will be interconnected, it is expected that the next frontier in the maturation of the sector of information and communications technologies will need to support the 1000x traffic growth expected through 2020 [1], [2] and will be based on a new system offering service delivery across a variety of scenarios that cover enormous variations in demand to and from the Internet.

In fact, according to Cisco forecasts [3], the number of global mobile users will reach 5.5 billion in 2020, which is expected to rise by 12% compared to 2015. In addition, the average mobile connection will increase to 6.5 Mbps in 2020 compared with 2.5 in 2015. Given this rapid evolution of wireless devices and the serious demands of high-speed communications [4], [5], it is promised that the future generation of mobile networks will make it possible to achieve these objectives while allowing the standardization of connectivity of people and objects, the maintenance of critical and massive machine connectivity, the supply of new frequency bands and the provision of extremely high-speed mobile telephony services [6]. Therefore, one of the primary targets of these mobile networks is to respond holistically to the demand for projected mobile traffic and to the communications needs of most sectors of the economy, which have increased since the turn of the century. These networks will not be an evolution towards another technology, but they will lead to the convergence of all the existing technologies towards a new infrastructure, where wireless technology is going to be a necessity for a large number of products in various sectors and not just an interesting functionality. This need arises from the potential of the data to accumulate. These data can become useful information that will allow higher orders of intelligence in various social sectors.

However, this growth of communications traffic will contribute to an increase in energy consumption that will account for approximately 4% of the global CO2 emissions by the year 2020 [7]. Therefore, energy consumption will be an important economic cost factor for future wireless networks and will pose crucial challenges for creating green networks that aim to reduce CO2 emissions. This survey identifies the essential paradigms that are the key enablers of energy consumption for the next mobile generations. An overview of the current state of the art is provided.

A. HOW TO PUSH CAPACITIES?

Following the Shannon formula related to the capacity expression, an increase in capacity is mainly caused by a rise in the bandwidth. However, considering the limited bandwidth and spectrum resources - to address the increased number of mobile broadband subscribers and the excessive

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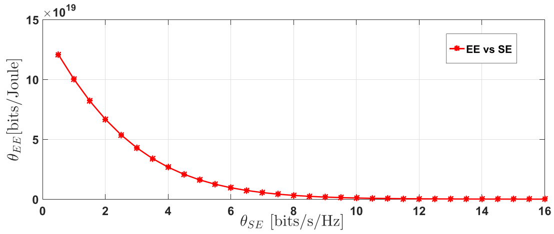

FIGURE 1. **Tradeoff energy /spectrum efficiency.**

service demands for future wireless mobiles - the effective planning of the network is a primary issue that should be considered. Thus, capacity can be expressed as follows:

$$\underbrace{C}_{\text{bits/s}} = \underbrace{\text{Spectrum}}_{\text{Hz}} \times \underbrace{\text{Spectrum efficiency}}_{\text{bits/s/Hz}} \times \underbrace{\text{Spectrum reuse}}_{\text{No units}}$$

Consequently, to address this challenge and achieve the capacities that satisfy the exponential growth of data traffic, while maintaining the required levels of Quality of Service (QoS) in terms of Low Latency Communications (LLC), improving the capacity can be realized based on the use of a new radio spectrum (spectrum resource), a new spectrum access scheme (spectrum efficiency), and a new infrastructure based on the SCS (spectrum reuse :dense heterogeneous network) [8].

B. WHAT CHALLENGES?

Obviously, the increase in network capacity by improving the Spectrum Efficiency (SE) and adopting new efficiency deployments aims to meet the exponential growth in future mobile services, but what about Energy Efficiency (EE)?

Based on the relation between EE and SE defined as [9]:

$$\theta_{EE} = \frac{\theta_{SE}}{(2^{\theta_{SE}} - 1)N_0} \tag{1}$$

where θ_{EE} defines the EE, which presents the achievable data rate per unit of transmitted power expressed in bits/sec/watts and θ_{SE} defines the SE, which represents the network throughput by a unit of bandwidth expressed in bits/sec/Hz.

Clearly, the challenging tradeoff between SE and EE is depicted in Fig. 1.

Furthermore, the Deployment Efficiency (DE) for a dense network deployment that measures the system throughput per unit of deployment cost, as proven in Fig. 2, faces the same crucial challenge relative to the EE. Considering that DE is the sum of a CApital EXpenditure (CAPEX), which integrates the cost of the network infrastructure (for instance, the installation of a Base Station (BS), the backhaul transmission, etc.) and the OPerational EXpenditure (OPEX), which includes the costs of operations (such as intervention, maintenance, electricity, etc.), the second challenging tradeoff between DE and EE is shown in Fig. 3 [9].

Evidently, the network density will lead to an increase in network capacity. However, the increase in the number of cell stations increases the backhaul power consumption [10].

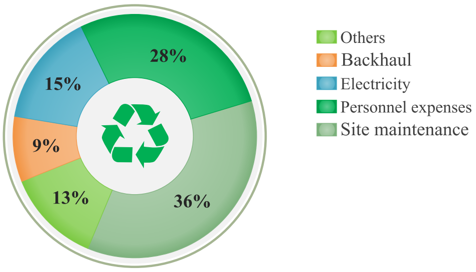

FIGURE 2. **Network OPEX distribution.**

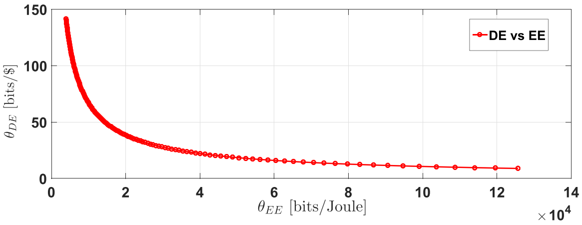

FIGURE 3. **Tradeoff energy/deployment efficiency.**

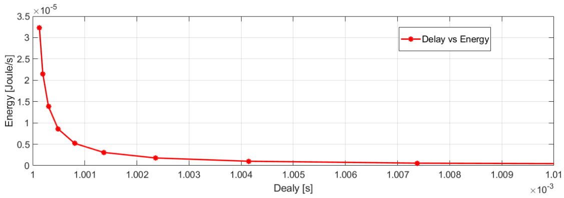

FIGURE 4. **Tradeoff delay/energy consumption.**

Moreover, guaranteeing a target delay QoS leads to significant power consumption assigned for the transmission. As depicted in Fig.4, the lower-delay requirement, the higher energy consumption and the lower energy efficiency is proved. Therefore, another fundamental tradeoff between the EE and LLC constraint is defined.

Thus, the major concern for mobile operators is improving the network capacity by enhancing the SE and DE that maintain the required QoS constraints based on the LLC concept, while keeping the EE metrics as an essential critical issue for mobile networks. Therefore, improving energy efficiency will be the most important area requiring new innovation for wireless standards.

C. CONTRIBUTION

To meet extremely high future demand and Key Performance Indicators (KPI) (Table 1) requirements for green 5G networks, the increase in SE and cell station densification – while maintaining the performance delay within the required limit – is urgently triggered. However, the implementation of these techniques will create EE challenges. Hence, to reap earnings from the next mobile networks, energy efficiency has to be optimized. In this context, this survey aims to identify the relevant research that needs to be considered, as illustrated in Fig.5. Thorough overview, summarizing the main promising green solutions, is provided (Table 4).

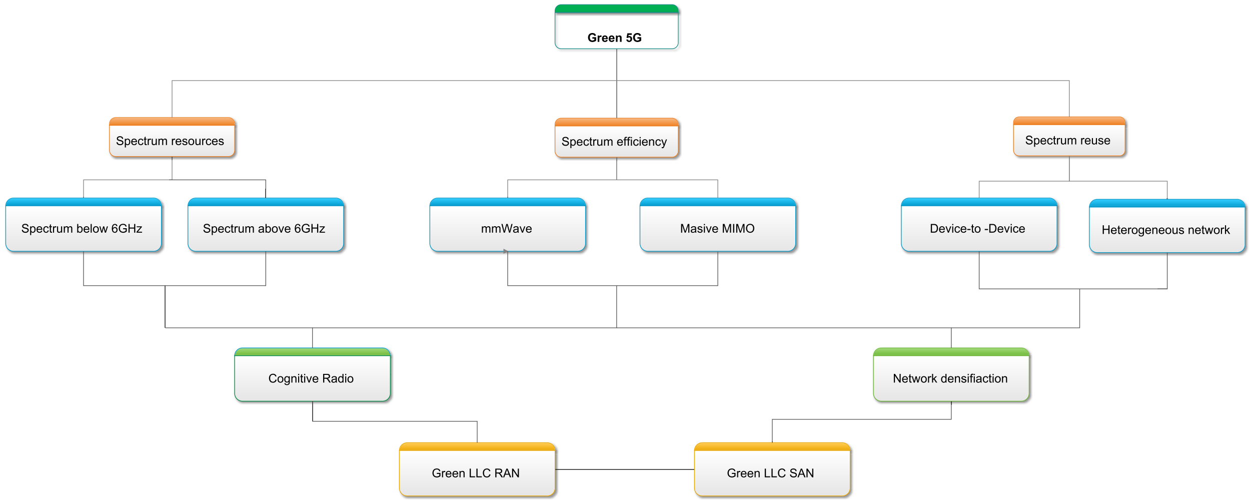

FIGURE 5. Green key technologies.

TABLE 1. Future network services.

Service	KPI	Spectrum resources	Target values
Extreme Mobile Broadband (xMBB)	**High data rates, LLC, extreme coverage**	**Lower bands + new higher bands with large contiguous bandwidth + (license + LSA + LAA)**	**Peak data rate up to 20Gbps(DownlinkL) and 10 Gbps (UplinkL)**
Massive Machine-Type Communications (mMTC)	**Dense mobile network, support wide area coverage, deep penetration (ex sensor network)**	**lower bands frequency + LSA + LAA**	**Connective density ∼ 1,000,000 devices/Km^2**
Ultra-Reliable and Low Latency Communication	**ultra-reliable, low-latency, communication links e.g.V2X communications**	**lower bands + exclusive license**	**User plane latency∼ 0.5ms**

The rest of this paper is organized as follows. Section II discusses the research that meets the green 5G capacities. Section III discusses the most effective solutions that aim to achieve a desirable and flexible tradeoff between EE and SE as well as EE and delay. Section IV concludes the paper and considers additional perspectives.

II. GREEN KEY 5G TECHNOLOGIES

A. SPECTRUM RESOURCES

Approximately 1.7 GHz of an additional spectrum is estimated to be necessary to fill the spectral resource deficit in 2020. Therefore, an additional new band must be defined (above 6 GHz), and new spectrum access schemes should be developed. Access to these resources will depend on the nature of the executing service. Reference [11] defined three types of 5G typical usage scenarios, as shown in Table 1.

1) SPECTRUM BELOW 6 GHz

- Authorized Shared Access/Licensed Shared Access (LSA)
  Unlike the traditional spectrum access system, which is based on the static allocation of the spectrum license to separate geographical areas, LSA (proposed by QUALCOMM and Nokia) represents a new form of dynamic spectrum sharing. This ensures the reuse of traditional spectrum resources under exclusive licensing and the management of free tapes that are not used by primary users (licensed to access these tapes). Indeed, secondary (non-licensed) users can benefit from these free resources without disturbing the primary users (licensees). The allocation can be temporal or spatial. Therefore, a new database is needed to collect the unused free bands (time mode) and the zones away from the primary zone (spatial mode). The originality of LSA stems from the fact that these restrictions must be defined precisely, in advance, by the administration.
- Co-primary shared access
  This access-to-spectrum concepts [12] represents the sharing of the frequency band between a set of systems (operators) of the same regulation and with similar rights to access the spectrum. A mutual agreement between the users of the spectrum based on a set of negotiating rules is necessary.
- Light license
  Light license access is attributed to limited users. This authorization system requires users to pay usage costs

TABLE 2. Spectrum above 6GHz.

Pparameter	Frequency band (6-20)GHZ	Frequency band (20-40) GHZ	Frequency band (40-100) GHZ
Data	2-5 GB/month	5-10 GB/month	20-50 Gb/month
User throughput	8 Mbps	10 Mbps	10-20 Mbps
Spectrum	2x120 MHz	2x140 MHz	2x160 MHz

TABLE 3. mmWave affected bands.

Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9
24.25-27.5 GHz	31.8-33.4 GHz	37-40.5 GHz	40.5-42.5 GHz	45.5-50.2 GHz	50.4-52.6 GHz	66-76 GHz	81-86 GHz	92-95 GHz

and register their used band with the regulator. It is characterized by an individual frequency requiring high and fluid demand, such as maritime mobile services, fixed and broadband wireless access base stations in dedicated bands (e.g., 5.8 GHz), as well as repeaters in public cellular systems.

Although it is evident that a new concept of access management for the entire spectrum needs to be developed, such as LSA and License Assisted Access (LAA). The use of these types of access depends on the nature of the service being performed.

2) SPECTRUM ABOVE 6 GHz

Future wireless networks are likely to provide high bandwidth and broadband speeds that are much larger than those in the current generation. Thus, the use of large blocks of the spectrum is necessary to reach these speeds. Bands below 6 GHz have already been identified for future mobile services. However, large spectrum blocks are difficult to find at low frequencies. Therefore, based on the strong correlation between the bandwidth of a signal and the data rate to be realized, high-frequency bands are also likely to be important in obtaining significantly increased data rates for mobile broadband. Thus, bands above 6 GHz have a more realistic possibility of meeting these requirements than bands below 6 GHz, where there are larger contiguous frequency blocks, and the spectrum is less fragmented.

The identification of these types of bands is mainly based on two premises: an initial (primary) allocation plan for mobile radio services and contiguous bandwidths of at least 1 GHz should be included. According to [13], the spectral bands that result from the application of the initial criteria (an existing primary global allocation to the mobile service and a contiguous bandwidth of at least 1 GHz) comprise approximately 60.8 GHz of the spectrum, as mentioned in Table 2. These bands cover the civil and military spectrum to ensure completeness and consistency.

However, these bands, as indicated in Table 2, have been already used for other services and dedicated to specific users. Finding the correct spectrum that best suits the users' needs without compromising existing uses is a critical challenge.

Certainly, a great deal of interest will have to be focused on sharing the spectrum with different methods. Moreover, low-latency and ultra-reliability will be among topics of concern in future wireless communications.

B. SPECTRUM EFFICIENCY

1) mmWave

Most wireless systems operate at frequency bands below 6 GHz. As mentioned in the previous section, to fulfill the needed 5G capacities, the exploitation of a spectrum above 6 GHz will inevitably be required. The millimeter wave spectrum, mmWave, presents an extremely high frequency designed for a frequency band from 30 GHz to 300 GHz.

In 2015, the International Telecommunications Union (ITU) [14] released a list of proposed feasible frequencies between 24 GHz to 95 GHz as provided in Table 3.

The mmWave presents a promising significant solution for 5G cellular networks. It provides very high throughput and improves the spectral efficiency due to the larger bandwidth. Moreover, the limited interference and the small antenna size enhance energy efficiency.

However, given the short wavelength, which is in the range of 1 mm to 10 mm, and due to higher attenuation and propagation losses, this band is available for short-range communications. Furthermore, diffraction and penetration through obstacles are difficult and can readily be absorbed or scattered by rain, foliage and gases. In fact, the license-free and standard-ready 60 GHz is an attractive solution. However, the oxygen absorption of electromagnetic energy in this band is approximately 15 dB/km, which is a much higher degree than in the other regions of 30-160 GHz [15]. This absorption significantly weakens the propagation of the 60-GHz signal over distance, making distant users unable to receive these signals. To this end, the mmWave is more suitable for use in securing indoor high-data-rate communications, such as hot spots. In addition, many base stations are necessary to cover a given zone, leading to higher site rental and backhaul costs, which become increasingly prohibitive.

Certainly, adopting spectrum reuse and limiting the amount of interference are required for short transmission paths and high propagation losses between adjacent cells. In addition, the use of small antennas to concentrate signals into highly dynamic focused beams seems necessary, e.g., longer paths to overcome propagation losses.

Due to the high attenuation of approximately 21 dB [16] and 28 dB [17] of 28 GHz and 60 GHz bands, respectively, the high path loss is among the most crucial challenges for mmWave techniques. Thus, to address the challenges, extending the coverage area through the use of multihop cooperative relay networks can significantly enhance network performance. For a short-range device, the utility of using 60 GHz as a backhaul has been proven. Hybrid architecture consisting of the simultaneous use of optical fibers and a wireless transmission method has been utilized, and performance has been depicted compared to the E-band. Considering the joint power allocation scheme, the optimal cost on deinstallation and the channel scheduling [18] optimize the wireless backhaul network. Based on the linear relaxation and the branch-and-bound algorithm, the ensuing mixed integer nonlinear programs have been solved. The authors in [19] studied the optimal deployment scheme for a green 5G wireless backhaul targeting maximum network throughput. Different energy efficiency scenarios of wireless backhauls for variant network architectures and frequency bands were presented and discussed.

Furthermore, the fusion of mmWave technologies and microwave frequencies introduces the current networks. Access technologies present an interesting backhaul model to improve EE. Aiming to maximize the throughput and minimize the energy consumption, the authors in [20] suggested a network infrastructure that supported WIFI (2.4 GHz) and mmWave bands. An omnidirectional antenna operating in the 2.4 GHz range was used to manage the procedures, and a directional antenna operating in the 60 GHz band was utilized for data transmission.

The authors in [21] discussed EE and SE of an mmWave beamforming structure. Two infrastructures were adopted and reviewed: the hybrid analog-digital-precoding-combining scenario and a combination with low-resolution analog-to-digital converters. To address the path loss issue, the analog beamforming architecture was used for short-range transmission. However, to improve performance, the hybrid beamforming structure was suggested for 5G communications.

2) MASSIVE MIMO

The Massive Multi-Input Multi-Output (MIMO) user [22] is a key technology driver that improves spectrum efficiency. It is manifested by the use of a large number of antennas at the base station (up to a few hundred antennas) to serve, simultaneously, a higher number of users with the same time and frequency resources as well as a large multiplexing gain and an array diversity gain. Compared to conventional MIMO systems that use large beam sectors, which require Higher Power Amplifiers (HPA) which consume most of the energy of the base station, massive MIMO utilizes narrow beams to direct wireless energy to target users. Hence, there is no need for HPA that consumes most of the energy.

The main objective of massive MIMO is to increase throughput, spectrum efficiency, reliability and energy efficiency. Among the most importing massive MIMO techniques that will improve energy performance in future mobile networks is the use of a large number of antenna elements for very selective beam-formed transmission [23].

Furthermore, selective beam forming methods decrease the amount of interference resulting in reduced overall transmission power in networks and extend the coverage area to provide high data rates in sparse deployment.

In addition, due to massive MIMO, the radiated power will decrease when focusing energy to targeted mobile users. Thus, the use of narrow beams for massive MIMO can replace the conventional system HPA, which provides a gain in terms of costs and energy consumption [24].

Several studies have proven the benefits of adopting massive MIMO for future mobile networks. In [25], a comparison was conducted between the performance of current long-term evolution macrocell BS architecture and a massive MIMO base station infrastructure. Using 128 antennas at a macrocell BS, the EE performance can increase by up to three times. Additionally, the authors in [26] showed that the deployment of a massive MIMO system with 100 antennas simultaneously serving a user was more efficient in terms of EE compared with a reference system with a single antenna as well as a conventional beamforming system, also with 100 antennas. Moreover, based on asymptotic SE and the realistic power consumption model for massive MIMO, it has been demonstrated that to obtain the same performance as a corresponding single-input single-output, a single antenna user in a massive MIMO system should scale down its transmit power proportionally to the number of antennas at the BS with perfect Channel State Information (CSI) or to the square root of the number of BS antennas with imperfect CSI.

It was proven in [27] that based on the narrow beams directed between the transmitter and the targeted receiver, massive MIMO provided an improvement in energy efficiency, which reduces the radiated power and decreased the interference to other users.

Under the assumption of a larger number of base station antennas, compared to user one's scenario, massive MIMO presents a high Degree of Freedom (DoF), which serves for signal shaping. In fact, each antenna can transmit signals with a constant envelope under very modest accuracy in terms of the total amount of radiated power using cheap power-efficient amplifiers [28] and [29].

Based on the sleep mode approach, the massive MIMO technique can improve EE by approximately 50% [24]. The main idea of this scenario is to adapt the consumption energy to the traffic load, the base station location, the coverage and the propagation environment, rather than the daytime traffic. Indeed, daytime traffic changes between areas; for example, an industrial area has different traffic and peak time when compared to residential areas.

Despite many benefits when using the massive MIMO technique, a set of challenges that are opposed to the achievement of desirable green architecture should be considered, such as:

- How can we conceive an extremely narrow beam that is not sensitive to the moving speed of the users?

- How can we realize a power-efficient RF amplifier that meets the necessary requirements in terms of high-frequency range, high-linearity and high-order modulation system?

-How can we achieve an ideal DoF for a green environment with a larger number of base station antennas and multiple users, which leads to more energy consumption?

-How do we characterize several properties of a channel and what analytical channel models could be used to modulate and analyze a massive MIMO system?

- What pilot contamination pre-coding techniques and algorithms can be used to satisfy the unbounded number of antennas?

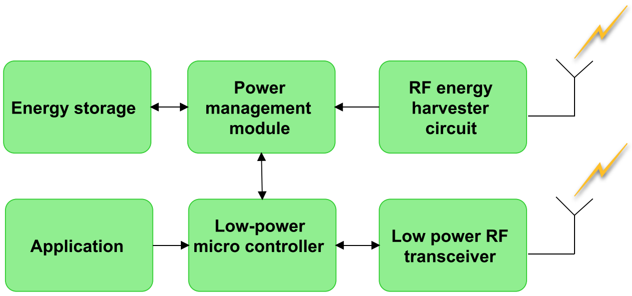

FIGURE 6. Energy harvesting architecture.

C. SPECTRUM REUSE

1) DEVICE-TO-DEVICE

The device-to-device (D2D) technique is part of machine-to-machine communications. This method initially serves to share data between users who are close to each other and to extend network coverage. Clusters of users are established when devices are in close proximity, hence the traffic offload on the base station. Two cases are presented [30]: i) the case of a relay cooperative mode where a device could be selected as a Gateway Device (GD) to relay with the base station (operator) or with another device ii) the case where the GD can assist direct D2D communications with the base station or with other devices. It is clear that two transmission designs are presented in the case of an infrastructural mode in which the operator is involved and the ad hoc case where no cellular networks are required.

D2D communications aim to realize load balancing and to improve energy efficiency and QoS, hence, the desired green wireless throughput. However, the major crucial challenge that opposes D2D communications is energy consumption [31]. Mobile devices are faced with battery constraint issues, which makes them incapable of sustaining 5G D2D communications for a long period [32].

The authors in [33] considered the challenging issue of the EE-SE tradeoff for D2D communications underlying heterogeneous networks and suggested a new framework to join the optimization of user power coordination and D2D pairs under imperfect CSI. A robust multi objective optimization problem was formulated and transformed to a single objective optimization issue resulting in an entire robust Pareto frontier. The simulation and numerical results evaluated the performance of the suggested method.

- RF Energy harvesting solution

  Using a range between 3 kHz and 300 GHz, electric energy can be gathered through electromagnetic radiation, which presents the RF energy harvesting approach. Moreover, the RF energy transfer is characterized by low power and a long distance. As a result, this method is more suitable for far-field communications, such as LAN, WAN and MAN wireless topologies.

  Several studies have been performed to adopt the energy harvesting concept. The authors in [34] derived the expression of energy harvesting for D2D cellular networks.

  The architecture of an energy harvesting device consists of six modules [35]: energy storage, power management, RF, an energy harvester circuit, an application layer, a low-power microcontroller and a low-power RF transceiver, as shown in Fig. 5. Exploiting the potential of RF energy transfer techniques, several studies have been conducted.

  A closed-form expression of D2D energy harvesting to define the outage probability was derived in [36]. The main idea was to harvest the energy from any wireless network node, such as BSs, relays, and small BSs. Although RF energy harvesting is a promising approach for future green 5G wireless networks, RF power transfer suffers from poor low RF-to-DC energy conversion efficiency regarding the low RF harvested power.

  A combined cognitive radio and energy harvesting infrastructure was used in [37], in which the secondary system could harvest RF energy from the transmitted signal of the primary system during the sensing phase.

- Cognitive radio solution

  Due to efficient spectrum reuse based on the dynamic spectrum access and the interference management scheme, the cognitive radio technique is the most promising solution for D2D communications [34]. Therefore, some work has proposed Cognitive Radio (CR) as a solution to save energy in D2D communications. A fusion between the cognitive radio and energy harvesting techniques was adopted for D2D communications in [34]. Two access schemes were proposed in this study. First, the author used random access to analyze the proposed model. Then the prioritized spectrum access scheme was suggested. The numerical results proved that the second model outperformed the first model, given that spectrum coordination was needed.

- Cloud architecture solution

  Adopting the cloud technology in D2D communications seems to be an interesting solution to realize energy efficiency for green 5G cellular networks [38]. Due to the data centers and the virtualization base system methods, energy consumption can decrease. Thus, several schemes have been suggested, such as generic static clouds [39], which are based on centralized architecture and hierarchical as well as non-hierarchical [40] cloud-assisted approaches that are based on the mobile dynamic cloud concept for HetNets.

2) HETEROGENEOUS NETWORK

In addition to the D2D technology defined in the previous section, the heterogeneous network presents another essential approach used for improving the spectrum reuse system. It is expected that networks will have to provide 1 GB of personalized data per user per day in a cost-effective manner by 2020. In addition, it is expected that 100 Mb/s services will be supported and that traffic will be up to 10,000 times higher than now. In contrast to previous systems of cellular generations, leading mainly to increasing the system bandwidth and improving the spectral efficiency, network densification [41] is one of the key technologies that should be exploited to support such a demand and meet the exponential needs of mobile traffic. Future networks will have to be very dense and multilayered so that they can provide significant advantages following the use of proximal transmissions, indoor/outdoor traffic and increased spatial reuse of resource systems. Nevertheless, when deploying an ultradense network, operators are faced with other challenges, mainly due to the characteristic interferences with newly adopted environments, different from those related to previous cellular deployments, to provide subscriber quality services while reducing the total cost of acquiring these types of networks.

In heterogeneous networks where different users with diverse QoS requirements and channels with various state and condition levels are considered, the Weighted Sum Energy Efficiency (WSEE) is used as the most attractive EE metric which provides more DoF for system design than conventional Average Sum Energy Efficiency (ASEE) that only treats the energy efficiency of the entire network. The authors in [42] suggests a joint power allocation and subcarrier assignments scheme leading to optimize the WSEE metric under imperfect CSI conditions. The expression of WSEE is derived function to the instantaneous transmitting power, the outage probability and the weight of each link. The impact of the imperfect CSI, the user circuit power consumption and the assigned subcarrier weight are investigated. The performance of the proposed scheme is proved compared with the energy efficient resource scheduling algorithm under a perfect CSI assumption.

III. GREEN TECHNIQUES

A. EE-SE TRADEOFF: GREEN COGNITIVE RADIO

Because all the exclusively dedicated frequency bands are not fully exploited due to the uniform spectrum distribution in terms of time, position and service, taking advantage of the existence of such unused bands is necessary for improving the spectral efficiency. Therefore, the idea of dynamically managing the naturally merged spectrum, which is the basic principle of cognitive radio. A so-called secondary user (SU) who does not have the right to access resources that are initially dedicated to the PU (PU) who is licensed, may at any time benefit from the frequency bands that are not occupied by the PU. However, this opportunistic use of the non-dedicated spectrums should not harm the PU. As a result, once the SU achieves its service or the PU needs to transmit, the allocated resources should be transferred to their owners.

This technology has been designed to be self-aware and autonomous based on the software intelligence embedded in the cognitive radio terminals. The latter must be able to sense the existing spectrum, analyze the sensed data and dynamically adapt to their environment. The secondary network will reconfigure according to the available existing free bands and their states (load, requested service for the PU, etc.).

Thanks to the cognitive radio networks, that the 5G network capacities will increase based on the shared dynamic spectrum resources between the primary and secondary networks [43].

However, this technology faces challenges that oppose the realization of the balance between energy efficiency and spectrum efficiency [44]. This is due to the unstable nature of the existing spectrum and the required quality of service.

What about the sensing phase?

To infer a specific database that contains precise knowledge regarding the radio environment, the information acquired by the spectrum sensing phase detection must be sufficient. Nevertheless, considering the dynamics and the temporal variation in the radio environment, the scanning speed and capacity to switch between different radio bands must play a very important role during the spectrum detection phase.

Such requirements impose strict needs on the hardware implementation of the cognitive radio equipment in terms of processing speed, bandwidth and RF circuitry as well as EE [45].

In addition, the techniques of listening to the environment, which are based on the listen-before-talking strategy that is necessary for sensing the unoccupied PU spectrum (white spaces), consume power similar to that consumed during the reception of data. Measures have proven that during the listening process, even with the use of economy modes, approximately 60% of the total energy consumption is used [46]. Thus, following the continuous process of this strategy in a cognitive network significantly increases energy. Research focusing on the sensing period has been overwhelmed; however, the limitation of this period will not guarantee perfect precision. However, a long period will be unnecessary since the environment is dynamic. To this end, it is interesting to revisit listening techniques in a cognitive radio network to reduce energy consumption.

What about the analysis phase?

Treating and analyzing the detected signals based on the learning algorithms [47] of high-complexity that enable fast and accurate decisions with a lower error rate consume sufficient energy.

Moreover, to improve the spectrum efficiency, efforts in the field of research and industry related to the spectrum

TABLE 4. Summary of the main green 5G driving factors.

Scheme	Benefits	Challenges
Massive MIMO	High SE and EE, large number of DoF	Pilot contamination, large numbers of CSI, hardware impairments
mmWave	Growth of network capacity, ultra-wide bands services, massive miniaturized antennas, massive connectivity	Multiple UEs access and coordination, shadowing, user mobility, integrated circuit and system design
D2D	Improving SE and EE, extending the lifetime of devices, decreasing operation cost	Interference management, unlicensed spectrum, massive devices connectivity
NOMA	Efficient use of limited network sources, energy efficiency, low latency	Strong Inter-Cell Interference (ICI), hardware complexity, error propagation in SIC
SAN	Energy efficiency, low latency, maximum throughput	Intelligent big data platform, security issue, new smart devices and applications: proactive components
NB-IoT	Sufficient coverage, low cost, power efficiency: high batteries life of about 10 years, massive IoT: connection density of about 1,000,000 devices/km	Complexities of deploying NB-IoT within legacy LTE Network, internal interference, security issues

detection phase through scanning at large frequency bands that span several GHzs have been discussed. Nonetheless, given the current technical means, these solutions remain costly and impractical. The detection of the spectrum based on such approaches will necessarily make use of complex transformation techniques - such as wavelet transforms - to extract the spectrum information from the broadband signal and to sample it at the speed of Nyquist. As a result, in addition to the complexity of the acquisition of such a quantity of samples, these techniques still suffer from the time required to process such digital signals to analyze the spectrum leading to a decrease in energy efficiency.

Obviously, guaranteeing a balance between the spectrum efficiency and the energy efficiency, in cognitive radio networks, is a crucial challenge that urgently needs emerging solutions dealing with the facing issue. Therefore, the interference control systems are essential to minimize the interferences and manage them. New innovation methods meeting the required EE are needed, as well.

A theoretical study on energy efficiency in a cognitive network was carried out by the authors in [48]. An outline of the broad issues referring to the need for energy management in cognitive radios was provided. The key aspects for energy control in all open systems interconnection layers were identified. It was shown that there were some modules or functions in the processing chain of each layer that influence energy consumption. A comprehensive view of the problems and solutions of energy consumption was conducted.

In [49], [50], a theoretical study of a cognitive radio system was carried out, mainly aiming to explain the set of factors directly affecting the problem of energy consumption. Considering a model based on the technique of waiting before switching and considering three constraints, detection precision, flow and SU latency, the authors - following their analyses - proved that the optimization of the detection time and the probability of the expectation of an SU would be closely linked to energy consumption. The detection was moderated by two probabilities. First, the probability of detection defined a busy channel such that it could result from a zero detection error, which was the inverse of the miss detection probability. The latter was related to the free detection of an occupied channel. Second, the false alarm probability defined an unoccupied busy channel, which brings us back to the problem of spectral inefficiency. These probabilities were proportional to the detection time of the SU. A short detection time decreased the probability of detection and increased that of the false alarm due to the lack of detection accuracy. However, a long detection time improved the accuracy, but it was to the detriment of the duration of the assigned transmission.

Once the detected channel is busy, does switching to another channel require more energy than waiting for that same channel until it is free? Or is it completely the opposite? According to [49], switching to another channel consumes more energy than waiting to release the busy channel detected, but this is the opposite for the transmission time allocated to the SU. Although the optimization of the sensing time s, as well as the probability Ps, reduces energy consumption, there are other factors that have not been considered, such as the delay caused by the transfer of spectrum, which consumes more time and energy. In addition, the cases in which several channels are detected: Which of these channels should be selected? What about the collision issue concerning the selection of the same detected channel by more than one SU?

To this end, other solutions have been proposed for the CR Networks (CRN), which treat practical cases based on the design of control strategies aiming to reduce energy consumption.

The authors in [51] proposed a technique, called the confidence vote (CV), to eliminate unnecessary information to save energy. Unlike traditional methods in a centralized architecture where all the information - gathered by the SUs - was transferred to the central node to start the decision step, this technique only allowed data from a trusted user who was able to detect the information with more precision. Although 40% of the energy was preserved when applying the CV method in the cognitive radio network, the energy consumed by the SU who was constantly sensing their environment - but who was not considered a reliable user - had to be considered.

Another technique in [51], called Cluster-Collect-Forward (CCF), addressed the problem of energy efficiency in the CRN. The basic idea of this work focused on adding two essential elements to the CRN. The first element was the local CVL nodes that presented the randomly selected local node, and the second node was the central CVC node that collected the information sent by the CVLs to save energy. According to their positions, the SUs formed a cluster from which one node is randomly selected to present the CVL. Each element of this cluster sends its information to the CVL. The CVL collects this information and distributes it to the CVC. Once this information was received by the central unit, the decision on the spectrum would be made, and the results would be retransmitted again to the CVLs, which in turn would retransmit it to their SUs. The reduction of energy consumption resulted from the decrease in transmission rates. Obviously, the use of the CCF technique improved the energy efficiency by saving energy. However, the problem of collision between the SUs was not addressed, despite the fact that it acted directly on energy consumption. Therefore, considering the mechanisms of synchronization and admission control to remedy this type of problem was needed.

Reference [52] suggested an admission control strategy to deal with the problem of collision, described previously. In fact, this technique required a waiting period for new users until the arrival of a slot so that their admission could begin. The Markov chain was utilized as a mathematical tool for the numerical analysis to examine the performance of this proposition. The simulation results demonstrated the positive impact of this solution on the probability of blocking and the efficiency of energy while decreasing energy consumption.

In a study extension by the same authors in [53], they proposed a technique based on a virtual reservation to improve mobile efficiency and maintain narrative links. It aimed to maximize the cognitive network throughput via the full use of the spectrum. An improvement in performance in terms of the probability of blocking the flow of cognitive users was shown. The exploitation of the control protocols in the MAC layer is an attractive solution to ameliorate the performance of the CRN in terms of energy efficiency. Due to this technique, interference can be avoided through the creation of synchronization between different users and the use of spectrum admission management.

Reference [54] proposed an eco-energy MAC protocol for the CRN. This common control protocol was based on a detection algorithm operating according to two modes. During the first phase, a fast and unspecific scan of the spectrum was performed. Once a change in the information collected between two successive scanning phases was detected, the transition to the second phase would be triggered to perform not only a more precise scan but also a more powerful one. This strategy stored energy by relying on a dynamic scan depending on the accuracy of the detected information. However, adopting a centralized architecture was too complex for a large dynamic network.

Reference [55] focused their work on conceiving admission control in a decentralized cognitive system. They used a dedicated common control channel based on the CSMA/CA technique to exchange control messages such as Request to Send (RTS), Clear to Send (CTS) and ACKnowledgement (ACK) packets. Initially, a cognitive node would ensure the existence of a frame of data transmitted by a certain channel. This verification of the spectrum could remedy the problems of conventional transmissions (collision, congestion, saturation, etc.). Then the collected spectrum information would be transmitted and acknowledged utilizing the RTS/CTS mechanism. If a neighbor node wanted to transmit, it had to wait a certain short inter-frame space time interval before transmitting its ACK message. Nevertheless, these dedicated protocols refuted the dynamic nature of cognitive networks. In addition, the dynamic common control protocols appeared as a solution that was more adapted to this type of network. This is why a cooperative spectrum approach has been introduced in several works to contribute to better detection accuracy and precise decision making.

Reference [56] proposed a framework based on the cooperation between a set of SUs. Each of them detected the unoccupied bands and selected the best among them to exchange it with the central base station. The BS, having gathered all the information concerning the best channels selected by the cooperative user set, selected the common control channel following an SVM classification algorithm. This protocol improved energy efficiency as well as the transmission rate.

However, other insufficiencies were not noted. For instance, the cooperation phase did not include all the SUs, which was reflected in the reliability of the common control channel selection. Yet, when broadcasting a common control channel selected by the CRBS, users who did not participate in the initial phase would not have this information, and thereafter, they would continue to access the spectrum arbitrarily without having the information about the DCCC. It should also be noted that this protocol became saturated with the increasing number of SUs.

To achieve the desired green networks, studies need to be further expanded and other autonomous spectrum management and control protocols must be invented. These control protocols should offer to the SUs the opportunity to make more precise decisions on the use of the spectrum and to adapt themselves autonomously and automatically to their transmission policies while sharing spectral resources equitably with the other SU in the same CRN.

B. EE-DE TRADEOFF: GREEN ULTRA DENSE NETWORKS

Expanding the coverage area and reducing the interference through densification by adding a small low-power cell station in the macro network area are promising solutions for operators [8], [41], [57], [58]. This type of network is called a heterogeneous network. In contrast to the conventional heterogeneous network (HetNet) of previous mobile generations, which is defined as multiple interfaces of different radio technology access, the ultra-dense HetNet (UDHetNet) for advanced networks includes hundreds of additional nodes (pico, micro, femtocells, relays) which are deployed in local areas. This new infrastructure aims to enhance the overall

TABLE 5. Estimated UDHetNet parameters.

Parameter	Actual HetNet	Dense HetNet	UDHetNet
Site /Km^2	21 sites	26 sites	93 sites
Inter sites distance	395m	237m	112m
Traffic density	~1Gbps/km^2	~5Gbps/km^2	~40Gbps/km^2

capacity and to provide effective coverage, capacity expansion, and green radio solutions.

A UDHetNet is a network in which the sites are deployed everywhere, on street lights or at interior sites within 10 m of each other. This densification serves to unload the macro network and to improve capacity and coverage area. A case study by Nokia [59] showed that 1000x capacity can be achieved by using both small outdoor cells and small inside cells.

Assuming that 10^5 users/km^2 is the maximum number of users in the considered area and 10% of the traffic is considered during peak hours. Moreover, utilizing the Erlang formula (traffic theory), a simple calculation will lead to the estimation of the number of sites and the inter-site distances, as given in Table (5).

Obviously, to meet the required capacity beyond 2020, the number of sites may be over 100 sites $/Km^2$, which results in an inter-site distance of approximately $100m$. Thus, the densification of the network is meant to raise the capacity and provide users with an optimum quality while maintaining a minimum total operating cost (CAPEX, OPEX). However, it is inevitable that the network operators, following the adoption of this new type of deployment, face a much greater challenge in the future [60]: critical problems exist in the design and management of the network in terms of spectrum access, backhaul links, interference, and mainly in terms of energy consumption.

The coexistence between different nodes belonging to different levels of high–and low transmission powers and in an uncoordinated environment, without causing interference, is one of the main difficulties in the deployment of the UDHetNets [61], which in turn impacts the energy efficiency metrics. With the increasing number of cell station deployments and considering the impact of severe interference - keeping in mind the soaring energy prices - it is forecasted that energy will be the main design criteria for the next generation wireless access networks [62], [63].

To achieve these targets, specialized mechanisms for avoiding and managing interference are essential. Due to the unplanned use of small cell stations in the UDHetNet, a set of dead zones can be stated given the enormous amount of interference [64]. This interference can be classified into two categories:

- The co-tiers interferences, which are introduced by the simultaneous use of the same band frequencies by a set of cell stations that are included in the same tier.
- The cross-tier interferences resulting from the use of the same portion of spectrum by a set of cell stations in different tiers.

Classical interference mitigation techniques, such as power control methods including the Reference Signal Receive Power (RSRP) [65] and the Cell Range Expansion (CRE) [66], are no longer fit for a UDHetNet. This is because the RSRP method yields an unbalanced traffic load, and the CRE concept may degrade the system performance in terms of capacity and spectrum efficiency resulting from the severe Inter-Cell-Interferences (ICI), between the cell stations, across tiers and the intracell-interference within the same tier.

Additionally, it is agreed that the conventional Inter-Cell-Interference-Coordination (ICIC) techniques - defined in the LTE 8/9 releases [67] and aims to control the ICI through the use of radio resource management approaches - and the enhanced ICIC - introduced in LTE R10 [68] to coordinate the transmissions of multiple cell stations in the frequency and time domains based on the on-power control mechanisms using almost blank subframes (ABS) - are not considered as fully effective solutions in UDHetNets. First, this result is due to the nature of these networks, which are arbitrarily planned and dynamically deployed [69]. Second, when all small cells share the same ABS and are so close, intracell-interference becomes a serious problem. A dynamic ABS for each small station is proposed by some previous studies to avoid this type of intracell-interference [70]–[72]. However, in an ultra-dense heterogeneous network, keeping the macro base station silent during all the ABS that are accorded dynamically to various small cell stations causes a reduction in the allocated macro-user resources for data transmission, yielding spectrum inefficiency.

Moreover, related research on future wireless mobile systems has revealed that advanced MIMO techniques, as well as multipoint coordinated transmission or reception (introduced in the 3GPP release 11 [73] under the Coordinated multi-point operation appellation, can address the problem of interference. However, this issue is difficult because the signaling controls in a UDHetNet between the network levels are limited or may not exist.

Subsequently, given that the UDHetNet will drastically increase the number of small cell stations, research should be directed towards autonomous processes to decrease or at least not increase OPEX.

However, the growth of communications traffic from 50% to 100% will contribute to an increase in energy consumption in the communication networks [74]. Given that information and communications technologies (ICT) systems and devices account for approximately 2% of global CO2 emissions (according to European Commission studies 2009) [75], [76], this contribution is expected to increase to 4% by the year 2020 [7]. Energy consumption will also be an important economic cost factor for the UDHetNet. In fact, the main source of energy consumption in the mobile network is the base stations.

Therefore, given the increasing number of cell stations in the UDHetNet, future communications will experience another crucial challenge introduced under the slogan of the green network aiming to reduce CO2 emissions.

To this end, future networks and ICT systems based on the UDHetNet deployment must be designed to be as energy efficient as possible. Thereafter, with limited spectral resources, ultra-dense heterogeneous networks must be designed while considering the principle of the balance between use and energy efficiency.

Various aspects of energy conservation in communication systems, such as energy-efficient wireless transmission technologies, network architecture, protocols and opportunistic cognitive spectrum-sharing schemes, are under consideration.

According to some studies, the base station is the most energy-intensive element in the mobile network, given that 80% of the mobile networks CO2 contribution is attributable by the base stations [10], [77], [78]. Thus, reducing their power consumption can be an interesting solution leading to maximizing the network energy efficiency. Reference [79] suggested a base station closing technique. The higher power consumption portions were related to the circuits of the active base stations. Accordingly, reducing the amount of energy consumption by closing the inactive base stations was revealed as an interesting solution. It proposed two strategies to maximize energy efficiency based on the user access scheme and the subcarrier allocation technique. The simulation results proved a significant improvement in terms of energy efficiency compared to the traditional sleeping mode. Nevertheless, considering an orthogonal frequency-division multiple access MIMO small cell network, the ICIs are neglected assuming a non-overlapped sharing carrier.

To reduce the amount of energy consumption in a dense cell station (considered as access points), [80] put forward an energy strategy that adopted on-demand resource methods. As a result, this technique allowed dynamically switching, on or off, the stations according to their number of users, which was based on the loaded traffic volume as well the set of active users in the coverage zone. A green cluster was conceived based on a set of nearby cell stations. These stations recognized themselves through the use of controlled beacons. In the same slot of time, all the stations send beacons every second for another station. After that, each station collects the received number of beacons and the strength received from each other station. A station would be defined as a neighbor if the number of beacons and the strength received from this station were greater than a defined threshold of the average number of beacons per second and the threshold of the average signal strength of beacons. Although the use of this strategy improved energy efficiency, it faced a tradeoff between service quality and saved power. As they were large, the cluster coverage zone was greater, resulting in an increased change in saved energy but a little performance quality.

A solution based on the dynamic adjustment of the size of the cell station coverage area was proposed by [81]. Three parameters, which were the estimated user demands, the traffic load and the channel condition, were used to adapt the cell station size. Both distributed and centralized algorithms were conducted. In each case, the cell zone service could be implemented at the central station or distributed to all stations. The main function of this service was to detect and collect information relative to the three defined parameters. Once done, a decision about the cell zooming concept was conducted. Cooperation techniques and relaying methods were considered in the design of this strategy. This concept provided benefits in terms of energy efficiency by saving the consumed power. However, it was challenging to estimate the traffic load, given the significant variations of traffic volume due to fluctuations.

It is notably remarkable that in UDHetNet, the macro base stations have the higher transmit power compared to small cell stations. Actually, the user association scheme directly influences the amount of consumed energy. Addressing the user association issue to maximize energy efficiency is a significant contribution. Conventional solutions based on the RSRP are no longer fit for future mobile networks. The RSRP method aims to associate the user with the base station that offers the best signal interference plus noise ratio (SINR), resulting in unbalanced loading traffic between the stations that differ in the power transmitted in the UDHetNet [82].

To address this problem, the CRE method is defined to balance the load between the macro base station and the pico base station. This is conducted through the addition of a bias value to the RSRP of the pico station to extend its coverage area. Reference [83] proposed a CRE based on the RSRP mechanism with an adaptive bias to offload the macro users to picocells. However, the users in the range expansion were subject to an aggressive ICI bringing about the need for ICI coordination.

Reference [84] suggested a cell range expansion scheme in a k-tier HetNet with a bias value attributed differently among tiers and maintained in the same tier. The spectrum was divided into a set of disjointed parts that were assigned separately between tiers. This method mitigated the interference across tiers, but the co-interference was not addressed.

Although the use of the CRE approach solves the problem of the non-utilization of low power stations, a set of crucial challenges opposed this technique, such as the amount of severe interference that damaged the UEs located at the edge of pico and the difficulty of predefining a bias value adapted to all users in the network, given the different users' geographic distributions and the fluctuation of the base station traffic load [66].

To address this problem, [85] proposed a joint macro BS transmit power control and a load-aware user association mechanism in the HetNet utilizing a new frequency reuse mechanism. The allocated bandwidth of the macro base station was divided into two parts assigned to coverage and capacity. The transmit power of the band attributed to the capacity was dynamically adjusted to balance the loaded traffic between the macro and the remaining low power stations in HetNet. Using this technique, even if the macro base station reduced its transmitted power, the coverage zone would not be affected.

Reference [86] proposed a user's association and power allocation concept to maximize the energy efficiency metric in a two-heterogeneous uplink network. Unlike the classical mechanism that allocated the rate to the subcarrier based on an equal manner, this method attributed the highest minimum rate to the subcarrier with the highest channel-to-noise ratio. Numerical results indicated that the rate-proportional method considerably enhanced the energy efficiency.

Obviously, all the solutions mentioned above improve the energy efficiency by power saving concepts and interference mitigation schemes, but this is to the detriment of spectrum efficiency. The under-utilization of the spectrum actually leads to spectrum inefficiency.

C. JOINT EE-SE-DE TRADEOFF: GREEN COGNITIVE DENSE NETWORK

A possible solution to these problems should use the spectrum detection approach to identify any inactive physical resources. This concept of spectrum detection is not new, as defined before, but the characteristics of the UDHetNet probably require different novel approaches to sense, detect and utilize the unused spectrum. Consequently, the exploitation of cognitive radio in the UDHetNet is a promising solution aiming to achieve the desired balance between energy, deployment and spectrum efficiency.

Reference [87] addressed the downlink ICI problem in HetNet considering a set of randomly distributed small cell stations and macro base stations. The cognitive radio approach was the basis of this study. The macro base stations were considered the primary elements in this CRN, and the small cell stations were considered the secondary elements. Two scenarios for the design of the small cell stations were conducted. The first model was called the semi-cognitive scenario, where the small cell stations would perfectly sense the assigned macro base stations spectrum. The second one was called the full cognition, where the small station adopted a perfect sensing mode for the macro base station as well as the remaining small stations. This strategy improved the spectrum efficiency as well as the outage probability by reducing the amount of interference, which led to realizing the balance between the spectrum and the energy efficiency. However, the adopted method did not consider the miss detection and the false alarm probabilities resulting from a non-realistic sensing scheme. This was caused by the lack of coordination between stations and by the random deployment of small stations against this strategy.

Reference [88] used the same previous approach and addressed the same ICI issue by exploiting the cognitive radio concept. In addition to the perfect sensing model, the non-perfect sensing scenario was considered in this analysis. The stochastic geometry method was used to derive the outage probability of the assumed system model network. As a result, the outage probability formula was expressed as a function of the network architecture and topology as well as a set of network design parameters such as the adopted MAC protocol, the resource selection mechanism (how the users are scheduled and how the resource blocks are selected), the sensing technique, and the SINR target.

Reference [89] suggested a novel approach to manage interference in ultra-dense heterogeneous cellular networks. Virtual coordination based on the dynamic common cognitive monitor channel protocol to address the intercell-interference issue was proposed. A tractable and flexible model for coverage probability and energy efficiency for a typical user was developed through the use of a stochastic geometry model. The analyses of the performance of the suggested protocol were illustrated both analytically and numerically in terms of coverage probability and energy efficiency metrics. The numerical results are illustrated, proving the analysis and improving the performance of the proposed framework compared to the conventional model and the enhanced ICIC (eICIC). However, it is proven that an optimal number of deployed SCSs is necessary to achieve maximum energy efficiency in network design.

D. EE-DELAY TRADEOFF

Given that the latency is mainly defined by the time resulting from the available directional transmit packet from the user to the node [90], and to achieve the required end-to-end latency, drastic changes in the network infrastructures is urged. Motivated by [91], the radio transmission delay can be expressed as the sum of: i) the queuing delay which depends on the available and adopted resource allocation scheme (the maximum number of users multiplexed on the same resources, the traffic load, etc), ii) the time due to the frame structure (FDD, TDD, CDMA, etc), iii) the transmission processing delay that depends on radio channel conditions, interferences, etc. and iiii) the occupied processing delay of a node, which depends on its capability. However, targeting a low latency will be in the detriment of an increase in the required operate-network energy. Various approaches for achieving low latency in green 5G networks that address the EE-delay have been proposed. In the next sections these solutions are classified into two types: the Radio Access Networks (RAN) and the Self-Aware Networks (SAN).

1) GREEN LLC RAN

The suggested green LLC RAN solutions put forward a set of modifications in the radio area interface which depends essentially on the physical and medium access control layers.

- NOMA scheme

  As the number of wireless devices grows, the Orthogonal Multiple Access (OMA), which allocates limited orthogonal resources leading to the fairness problem, may not meet severe emerging requirements, including massive device connectivity, needed spectral efficiency and essentially low latency [92]. To deal with this issue, the Non-OMA (NOMA) technique emerges as a promising solution. It aims to improve the spectral efficiency while allowing a certain degree of multiple-access interference at receivers. In fact, to handle the user fairness problem, this method serves multiple users with different channel conditions [93].

NOMA schemes can be categorized into two modes: power-domain multiplexing and code-domain multiplexing. In the first scheme, various users, according to their channel state, are owed different power coefficients to achieve high system performance. In fact, different users' information signals are overlaid at the transmitter, and then Successive Interference Cancellation (SIC) is applied at the receiver in order to decode the signals and detect the desired signal, to avoid the user's fairness and improve the latency. However, in the second scheme, diverse users are allocated diverse codes and multiplexed into the same time-frequency resources.

Although the NOMA is defined as a promised solution to overcome the energy as well as the spectrum efficiency issue, it is difficult to serve all users by NOMA regarding the high complexity of SIC. To deal with this drawback, a hybrid solution based on the fusion of OMA and NOMA multi access systems is considered as an assured green 5G approach.

Reference [94] suggested a hybrid multi carrier NOMA and OMA multi access approach to deal with the EE-SE challenge. A joint power and resource allocation users clustering and subcarrier assignment algorithm under a minimum rate requirement constraint was proposed and a Multi-Objective Optimization (MOO) problem was formulated. To face the complexity of the non-convex MOO, a single-objective optimization issue using the weighted Tchebycheff technique is then considered. The performance of the proposed framework is proven until maximum three users share the same subcarrier. Compared with the conventional OMA and NOMA system, the suggested scheme outperformed in terms of EE-SE tradeoff.

To deal with the tradeoff SE-Delay, a hybrid NOMA-OMA multiple access approach was deployed in [95], where users grouped in pairs were served by NOMA; however, inter-NOMA-pairs-users OMA is used. Based on a statistical delay Quality-of-Service (QoS) requirements, a Rayleigh fading model with effective capacity for download NOMA networks was assumed to analyze the impact of the transmit SNR, and the total effective capacity for the two-user network as well as for M-users was considered and analyzed. Sustaining a required delay-outage probability, a closed-form expression of achievable effective capacity was derived and the performances of NOMA, at high SNR value, were proved compared to conventional OMA in terms of higher total effective capacity.

Joint user pairing, energy efficiency, low latency and user-sufficient QoS requirement were studied in [96]. Based to the hybrid use of OMA and NOMA, a dynamic algorithm was proposed to maximize the EE while achieving required spectrum efficiency and low latency communication. The queueing delay wais reduced through the dynamic control and it adjusted all the link transmission rates, where NOMA deployed the case of low queueing delay and high power consumption; yet the OMA system is adopted elsewhere. A scenario of two-users NOMA in a hybrid multi access system was considered and simulated to analyze the performance of the suggested scheme that outperformed the optimization OMA case.

- NB-IoT and mMTC techniques

The new promised radio access technologies, NarrowBand - Internet of Things (NB-IoT) and mMTC announced by 3GPP in Release 13 and 14 meet the requirement of low power wide area network connectivity. They aim to support the massive number of low throughput devices and offer better indoor coverage with low latency and ultra-reliability as well as low power consumption. However, the energy efficiency/latency tradeoff is presented as a crucial challenge that opposes to the whole NB-IoT and mMTC systems [97], [98].

Basically, to reduce the maximum transmission power, these systems uphold two power saving approaches [99], which are the Power Saving Mode (PSM) and the extended Discontinuous Reception (eDRX). In the PSM mode, the devices are registered into the network but not reachable on the idle states. Whereas, the sleep mode is switched off when the devices want to transmit data. The eDRX mode allows, in the idle state, users to adopt a deep sleep mode periodically (each eDRX cycle of about 175 minutes). At the expiration of the eDRX cycle, the devices switch to an active mode to listen to and receive a paging message from the network for expecting incoming data before.

Although the PSM and eDRX techniques aim to save energy, the communications latency becomes a crucial challenge for various traffic types.

Considering an mmWave broadband directional communications for green 5G, both power saving and lower latency are achieved using a sleep mode scheme of the directional DRX which is called a hybrid DRX and which consists of a beam searching concept when data packet intimation is active in [100]. The simulation results depict the performance of the hybrid DRs compared to the directional one in terms of average delay.

The authors in [101] dealt with the challenging issue between energy efficiency and delay by the dynamical adjustment of the DRX timer parameters, instead of the static traditional adjustment method. Based on the channel state and condition reported by the users as well as the users-experiencing average packet delay, two algorithms were proposed to dynamically update the DRX delay. Considering various service sceneries and applications, the performance of the proposed DRX method is identified in terms of delay and energy.

A new state model for green 5G is suggested in [102], which relied on the state of the RRC protocol. Indeed, a user ''Connected Inactive state'' was added to the old ''connected'' and ''idle'' states in order to reduce the delay taken by users when switching to an active state to save more time. Based on the concept of ''Not discarding previously exchanged information'', inactive users in the ''Connected Inactive state'' kept parts from the radio access network, hence avoiding the need of handling the UE mobility.

- MOO algorithm
  The expression of the EE is involved for realistic network communications, under different links with various benefits and costs that require several performances such as effective capacity, spectrum efficiency, low latency, etc. To derive the EE formula, two methods are defined, which are the Global Energy Efficiency (GEE) and Multi-Objective Optimization(MOO). GEE presents the ratio between the average sum of the individual link benefits and the total network consumed power. Nevertheless, it does not allow the design of the appropriate efficiency of the different network links. Therefore, MOO deals with that issue and allows reaching the individual energy efficiency for each node as multi objects to optimize under various performance factors.
  Maintaining a link-layer limited delay-outage probability and transmit power, [103], [104] coped with the challenging tradeoff between EE, SE and delay. A join optimization problem was investigated and analyzed through the formulation of a single-objective optimization problem gathered from the MOO problem. To achieve the optimal desired power allocation scheme, the weighted sum solution as well as the Charnes-Cooper transformation and Karush-Kuhn-Tucker (KKT) conditions were used. An appropriate weight, a normalization factor, circuit power and power amplifier efficiency defined the desirable optimum average power. Moreover, compared with the traditional water filling solution, the performance of the proposed solution were proved in terms of effective capacity at a small delay requirement.
  Reference [105] studied the tradeoff between EE and SE in massive MIMO-enabled HetNets under a backhaul capacity and QoS (required latency) constraint. A joint optimization of power and spectrum allocation, user association, QoS requirements and a free number of activated antennas framework was proposed. A MOO problem was formulated and transformed after that to a Single Objective Optimization (SOO) problem to solve the optimization issue. The numerical results showed an improvement in the EE-SE performance of the proposed algorithm, under QoS requirements, compared to the max-SINR algorithm.
  A smart sleep strategy was introduced in [106] to improve the energy efficiency in heterogeneous networks where two thresholds are used, a turn-on threshold and a turn-off one. The pico station was activated when the user's number is overhead the turn-on threshold. However, it would be switched on the sleeping mode when a user's number is below the turn-off threshold. The study of the performance of the proposed approach was investigated for three different architectures: the macro cell only network, the cell on edge and the uniformly distributed cells. Through the simulation and numerical results, the cell on the edge model outperformed the two other scenarios and an EE gain of about 20% and an SE gain of about 29% are proved compared to the conventional model while guaranteeing a constraint QoS in terms of low delay.
  Reference [107] employed an efficient energy scheme based on the separation of the control and the data plane where a lower total delay was allowed. It aimed to associate users with an appropriate station according to their required data traffic. Particle swarm optimization algorithms were applied to formulate the optimum solution. Thorough simulation results and examples were defined proving the performance of the suggested solution in terms of EE-SE and low latency.

2) GREEN LLC SAN

Although a Self-Organizing Networks (SON) is designed as one among the operational future approaches to improve network efficiency, it might not fulfill the 5G network requirements. Therefore, a new approach in the design of the network structure based on the artificial intelligence combined with the SON mechanism is triggered. Through the introduction of a higher level of automation in future networks reliant on machine learning techniques and software defined networking, the increased capacity will be managed. This new architecture based on the Self-Aware-Networks (SAN) can predict channel states, traffic loads and user demands in networks and make smart decisions and future guesses [108]. Hence, SAN will improve the quality of services and reduce CAPEX and OPEX through the dynamic fulfilling of the subscriber demands ensuring their requirements.

The SAN process covers four stages. Sensing the network and detecting the environment states in terms of loading traffic, users' demands, data and channel condition represent the first step. Thus, the next step is to analyze the gathered information in order to define free allocated resources, essential demands, priorities levels and required qualities. After that, the two most important phases is to make the best decision at the best moment and to predict actions for future anticipation, essentially. Obviously, SAN aims to achieve a desirable balance between the target quality, the low latency, and the energy and spectrum efficiency.

An intelligent automate self-organization green ultra-dense networks using a realistic traffic context based on the learning genetic algorithm is suggested in [109]. A multi objectives SON to predict a set of sub-optimal solutions dealing with the conflicting challenges in terms of wide coverage, low cost, low latency, energy efficiency, load balancing and awareness was proposed. Keeping the same capacity, latency, throughput and coverage targeted parameters, an improvement of energy efficiency was proved through the simulation. However, to cope with the complexity of ultra-dense future self-automation networks, the need of new emerging solutions such as big data, cloud, learning and mobile edge computing is triggered.

Reference [110] proposed an efficient delay-energy aware routing protocol for wireless networks. A wireless sensor and actuator networks were considered and classed into a set of clusters. The cluster with the higher energy and connectivity capability will be selected as a Cluster-Heads (CH). Each CH gathers the set of information from its sensors and could communicate with its neighbor actuator nodes. The CH had to identify the most efficient routing path reaching a neighbor actuator node to save time and energy. The performance of this approach is evaluated compared to other solutions.

To improve the energy efficiency metric by reducing the power consumption while assuring a targeted blocking probability and transmit delay, a sleep mode control algorithm for base station was defined in [111]. Based on the traffic-aware algorithm which resulted from the direction of arrival information of the UEs, active base stations could predict the area-directions of higher traffic loads and decide about the best time to switch on/off. Achieving the desired goals in terms of minimizing energy consumption guaranteeing required delay and a transmission rate was analyzed.

Reference [112] proposed a joint task offloading and bandwidth allocation Q-learning algorithm for multi-user mobile edge computing. An optimal solution that aimed to minimize the energy consumption and the total delay was conducted through the use of the deep reinforcement learning. The performance of the suggested algorithm was evaluated and proved compared to various schemes.

A smart architecture based on an intelligent agent was discussed in [113]. A SAN solution based on the fusion of sensing, learning and optimizing mechanisms was proposed to improve 5G key enablers. A set of artificial intelligence applications and methods for dealing with different issues of 5G network deployment and management were presented.

IV. CONCLUSION

The estimated increase in the number of wireless services and connected mobile devices in the coming decade, paired with the required quality of services for the emerging broadband services, has created the need for evolving solutions that effectively meet the required capacity demand. However, it seems that these technologies are encountering major challenges, especially in terms of energy efficiency. Thus, the most important question is how to create green 5G.

This paper has highlighted the key elements of 5G green networks, listed the previous work in this context, addressed the prospects offered by ongoing wireless developed approaches and paved the way for novel technique suggestions.

In summary, this work aims to answer the following questions:

- How should operators deploy their future network to address the expected capacity demand while considering the energy efficiency issue?
- How can we achieve the desired balance between 5G capacities and a 5G-friendly environment?

These studies in the field of green 5G have harnessed a novel paradigm and led to the development of other considerations for future wireless networks emphasizing the challenges that still lie in energy efficiency, even with the adoption of network densification technology.

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