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Green Communication in Next Generation Cellular Networks: A Survey

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ABSTRACT In order to meet the intense user demands, the 5G networks are evolving, and will be available by 2020. The unfolding cellular technology has raised the energy consumption in mobile networks with the carbon footprint surging to alarming rates. This is causing an adverse effect on the environment and human health. Addressing these aspects, this paper presents a survey on techniques for making the next generation cellular networks GREEN. A number of technologies form a part of the 5G networks, in order to support the drastic user demands, and are receiving substantial attention from the perspective of green communication. These include device-to-device communication, spectrum sharing, ultra dense networks, massive MIMO, and the Internet of Things. Also, a prime concern in the current scenario is the battery life of the mobile terminals. For enhancing the battery life of the user terminals, a proposal is given in this paper, with spectrum sharing as its basis, to overcome the energy crunch. Major research challenges have been discussed, and the ongoing projects and standardization activities also stated in this paper.

INDEX TERMS Carbon footprint, D2D communication, ultra dense networks (UDNs), massive MIMO, spectrum sharing, Internet of Things (IoT), small cell access point (SCA).

I. INTRODUCTION

The 4G networks are now reaching maturity, making the researchers head towards a new generation of wireless networks, the 5G. It will be a generation with extremely high carrier frequencies, large bandwidths and massive connectivity [1]. It is expected to provide 1000x more capacity, than the 4G networks. An unprecedented number of devices will be served by the 5G networks. The vision of an intensely connected network has been proposed in [33]. Such an enormous technological advancement [2] demands a rise in transmit powers. However, increasing the powers in not a smart step. This would result in a rise in the greenhouse gas (GHG) emissions. The projected carbon footprint until 2020 [9], of the mobile communications is illustrated in Fig. 1. It is thus necessary for the 5G cellular networks to take into account minimization of the energy consumption. A general 5G scenario is depicted in Fig. 2. These networks are expected to be deployed by 2020.

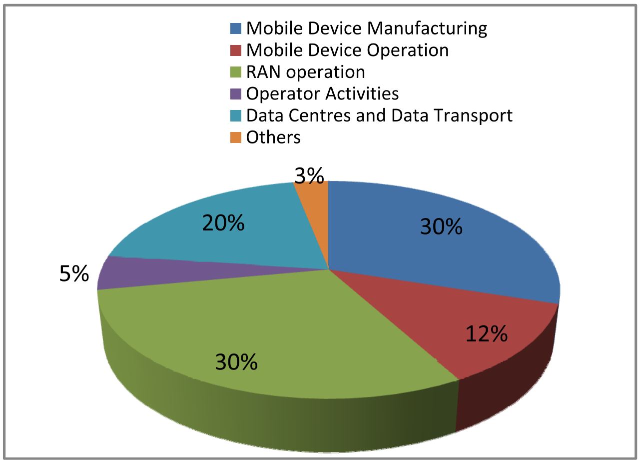

FIGURE 1. Carbon Footprint of mobile communication (projected in 2020).

The evolution of information and communication technology (ICT), during the last decade, is causing energy consumption levels to reach distressing rates. This has occurred due to the astronomical boom in the number of subscribers and the number of devices. The rise in the number of connected devices will be up to 100 billion by 2030 [3]. The major drivers of escalated traffic levels are the increased content-size and high data rate demanding applications [4].

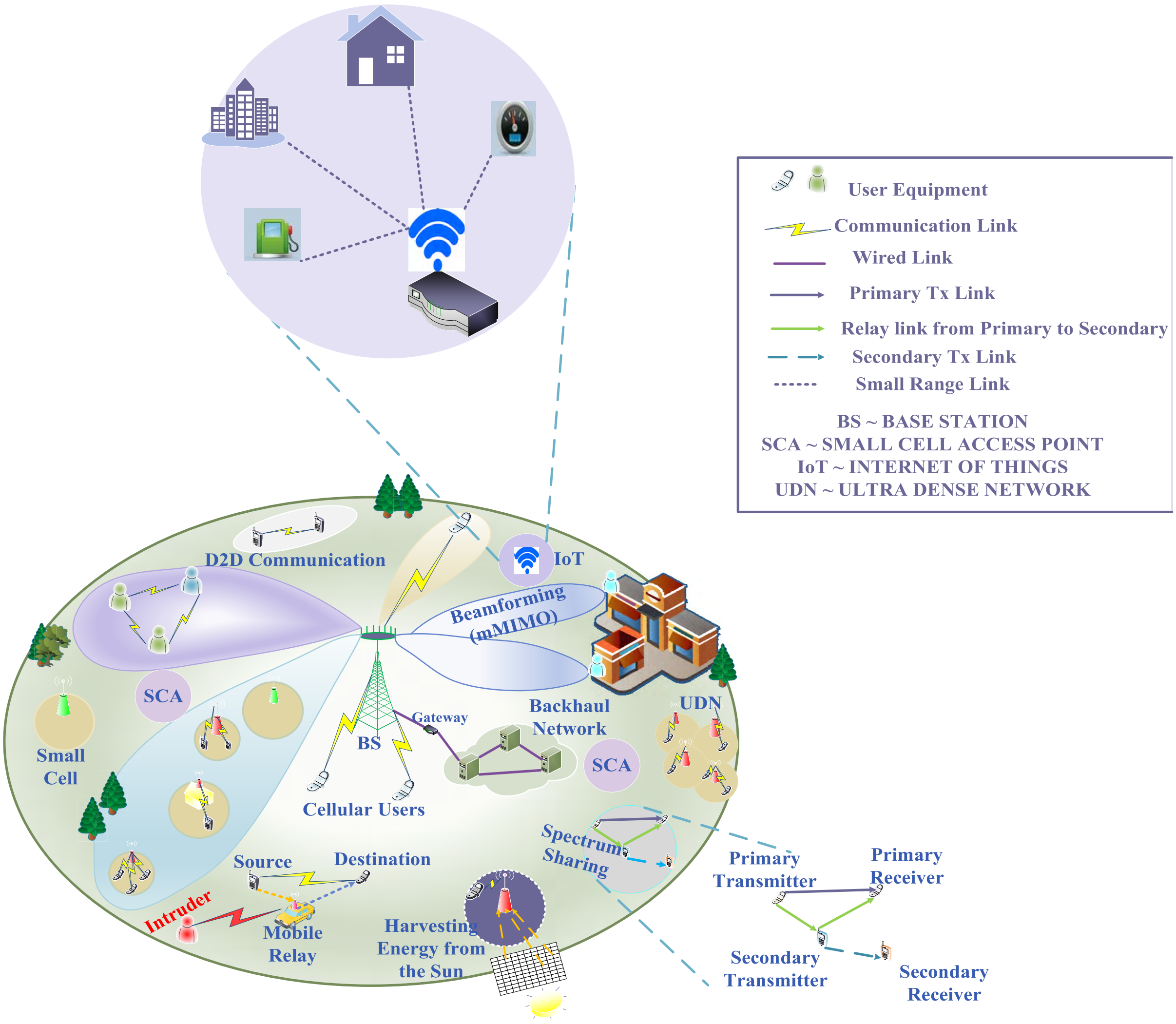

FIGURE 2. A general 5G scenario.

Major contributor to this augmentation is the rapid evolvement of smart phones, notebooks, tablets, etc. The percentage rise in the number of various devices is evaluated in [5]. This rising demand is greatly affected by the social networking sites as well, like facebook, twitter etc. The rise in the global mobile traffic is forecast in [5]. The massive connectivity is achieved at the price of prodigious carbon emissions into the environment. The amount of carbon dioxide (CO_2) emissions from the cellular networks will be 345 million tons by 2020 [7]. The tele-communication sector greatly contributes to increased CO_2 emissions, with its share being about 2%, at present. In spite of being a minute percentage, it is extremely substantial as this is expected to increase drastically in near future, if appropriate measures are not dwelled upon.

The mounting emissions are from the mobile devices as well as the radio access networks. The CO_2 levels in the atmosphere are expected to increase manifold, till 2020, highlighting a steep rise in its emission. This has been speculated in the SMART2020 report [8]. An estimate of the total emissions and traffic demands, by 2020 are predicted in [9]. With increasing carbon emissions, global weather is acutely being affected [10], causing rise in the global temperature. A corresponding rise in the energy bill is also considerable and Telecom operators cannot ignore their operational costs (OPEX). Of the total operational cost of a mobile network operator (MNO), 30% is the energy cost. Ecological and economic implications of the global CO_2 emissions have been deeply quantified in [9]. This calls for 'green communication'. Energy-efficient wireless communication (green communication) is imperative, looking into the whereabouts of the present-day scenario. A number of programs have been launched around the world, assenting green networking. Thus, in order to maintain the power consumption, energy efficiency needs to be improved in proportion to the escalating data rate, posing a serious challenge for the researchers.

Apart from the CO_2 emissions into the environment and cost factor, other reasons for heading towards green communication include rising health concerns and the battery life of devices. Human health and the environment [189] has been adversely affected due to the increased radiations. The radiations are absorbed by human body, specifically human head, which are indicated by the specific absorption ratio (SAR). A higher SAR is more harmful to human health. The SAR from different manufacturers varies. The values of SAR are regulated by various environmental authorities around the world.

Although telecom industry is rapidly growing, the battery technology is advancing at a comparatively slower rate. The improvement in battery capacity is around 1.5x per decade [11]. With drastic rise in the multimedia communication, the battery of smart phones is a major concern. This thus calls for the user terminals to be energy efficient.

The exponential rise in the number of users and the number of devices has surged interest in the topic of low-power, energy-efficient communication. The largest share of energy is that of the access network [12]. To keep the power consumption in control, following areas of research have been identified:

- *Resource Allocation*- Optimal resource allocation is the prime factor affecting the power consumption. Efficient resource utilization in time, frequency, and space has been reviewed. A number of resource allocation techniques have been studied in the literature, which are capable of optimizing the energy efficiency [13]–[17], through optimal energy saving. Trade-offs, however, exist, between energy efficiency and other metrics.
- *Optimal Network Planning*- Strategies for planning the network in an energy efficient manner include minimization of the density of base stations (BSs) for a certain coverage area [18] and using sleep modes for base stations (as discussed in Section III). Such strategies are required because as per the current scenario, the number of base station sites will be 11.2 million by 2020, significantly drawing energy and contributing towards the rise in CO_2 emissions.
- *Renewable Energy*- The share of diesel in the radio access network (RAN) power is expected to rise up to 13.2% by 2020, from 11.3% in 2014 [9]. Due to scarcity of fuel, using renewable sources for powering of base stations (BSs) is an intelligent choice [19]. A green energy enabled mobile network, the design and optimization strategies for these networks have been presented in [20]. The concept of energy harvesting has been introduced.

With the introduction of energy harvesting (EH), wireless powering of devices has become feasible. EH can be ambient or dedicated. It requires the availability of dedicated energy sources, thus it is unavoidable to sustain additional power consumption [21]. The deployment of EH networks need minute examining of the hardware devices required [22]. The integration of renewable resources and increased use of smart grids can abate up to 1.8Gt CO_2e. Projects for green cellular networks have been initiated all across the globe, heading towards energy efficient next generation cellular networks.

The maturing 4G standards have accelerated research in the 5G technologies. A number of consortia and research groups around the globe are involved in investigating energy efficiency in the next generation networks (NGNs). ITU's commitment towards green communication is remarkable. Its Study Group 5 (SG5) motive remains, go green [23]. Many of the 5G technologies have been addressed in 3GPP Release 13. Potential energy saving in 5G have been evaluated in Release 14 and 15 [24]–[26]. ETSI also contributes towards energy efficient cellular networks [27]. A number of projects for the development of 5G networks have been initiated by 5GPP [28]. The projects deal with energy efficiency, small cell deployment, security, cost efficiency of the networks (Appendix C). The various standardization authorities and their objectives have been listed in Appendix A.

A. CONTRIBUTION

Extensive surveys for enhancing energy efficiency and driving the ICT towards green communication have been studied in [29]–[32] and [34]. A detailed survey on 5G networks has been presented in [33]. The energy crunch in the networks can be averted by adopting novel techniques in the network design and operation, instead of scaling up of the transmission powers. Such techniques aim at improving the network energy efficiency 1000x. For various such approaches, the state-of-the-art has been provided in [30] and [32]. Diverse methods for improving the power efficiency of wireless networks have been presented in [29]. Numerous upcoming techniques for 5G networks have been surveyed in [31], primarily focusing upon relays and small cells for meeting the objective of green 5G networks. Bolla *et al.* [34] provide a significant contribution to the green networking, by surveying in detail, the various projects, ongoing activities and technologies for enhanced energy efficiency. In spite of the state-of-the-art available, the present day results of research remain preliminary with numerous existing challenges. A prolonged battery life of the user equipment remains unscathed. This is an important aspect to be addressed, in conjunction with network energy efficiency.

In this paper, a detailed survey on energy efficient cellular networks has been presented, in erranding green communication. Beginning with the impact of rising number and demand of subscribers, and their impact on the environment, power optimization at the base station is studied in detail. For analyzing the network, various energy efficiency metrics have been evaluated. Thereafter, the diverse 5G technologies have been studied (device-to-device (D2D) communication, massive MIMO, spectrum sharing, UDNs, IoT), which are capable of enhancing the energy efficiency of the future networks. A detailed literature has been reviewed, for all these technologies.

It is a known fact that the devices have a limited battery life, be it a smart phone, tablet or any other smart device. The existing research mostly investigates the energy efficiency

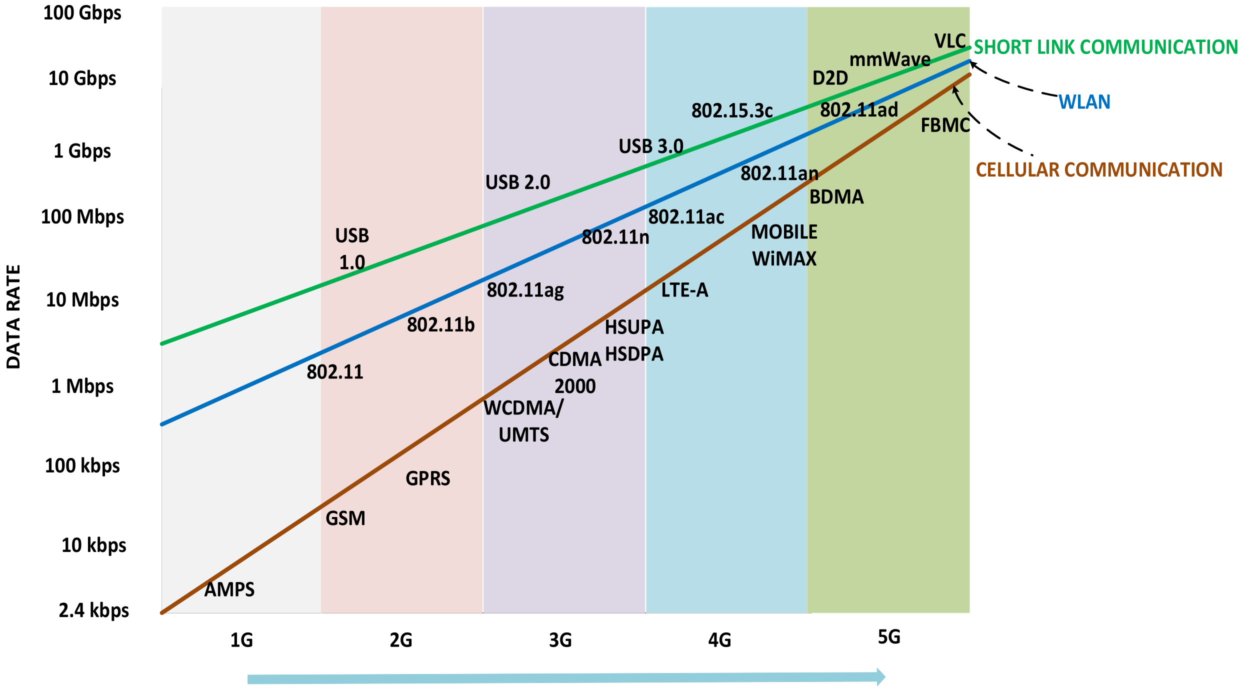

FIGURE 3. Journey of 1G to 5G (technology v/s data rate).

from the perspective of the MNO. As a result of this, the battery of mobile terminals drains at an accelerated rate. This can result eventually to high call drop rate. Battery is consumed less at low distance from the BS. Yet, having a low distance is not always possible. For a prolonged battery life, which is highly desirable, a proposal has been made in this paper, addressing the spectrum sharing scenario. The proposal will be an effective approach for having a longer battery life of devices, during the high demand sessions in spectrum sharing networks. Major research challenges in the path of a truly green network are also stated.

B. ORGANIZATION

The remainder of the paper is organized as follows: In Section II, the impact of the rising number of users and high data rate demands on the CO_2 emissions in the environment is presented. This aspect needs to be critically addressed. So, at the very first step, energy efficiency at the base station is sermonized in Section III. In section IV, power allocation techniques are briefly reviewed, along with the different energy efficiency metrics (the green metrics). Thereafter, different technologies are studied in Section V, which are capable of supporting green networking in 5G networks. The technologies include device-to-device (D2D) communication, ultra dense networks (UDNs), spectrum sharing, internet of things (IoT) and massive MIMO. The various associated research challenges have been discussed in Section VI. The paper finally concludes in Section VII. A list of research projects in process, based on the 5G technologies for energy efficiency improvement and carbon footprint reduction is shown in the Appendix C. Various standardization agencies have also been listed in Appendix A.

II. GREEN COMMUNICATION: THE EVOLUTION

In virtual sense, every human on this planet is using a mobile phone. To provide service to each and every user, the wireless communication networks are evolving at a fast pace. The global IP traffic is expected to be 120.6 Exabytes per month, in 2017. As a result of the rising traffic, carbon footprint is being greatly contributed by mobile device production and the operation of the radio access network (RAN). The rise in the carbon dioxide levels is three fold, from 2007 to 2020, as predicted in [9]. The wireless data is expected to be almost 10,000 times more in 2030, than it was in 2010. The rising data rates, through the generation, are depicted in Fig. 3. The explosive growth in the network traffic, globally, has resulted in a growing concern towards energy efficiency, which is emerging as a key pillar for the NGNs. Reducing the energy consumption in cellular networks is an economic incentive for lowering the carbon footprint globally.

To service such a volume of traffic, the network operating expenditure (OPEX) increases extensively. Large energy consumption has a direct impact on the CO_2 emissions into the environment. The variations over the generations on the rising CO_2 emissions are depicted in Fig. 4. The figure clearly depicts the rise in the amount of CO_2 levels with increasing traffic, over the generations of wireless communication. Micro cell deployment was initiated in the third generation, and thereafter, an attempt to decrease cell size has been encouraged, resulting in a rise in small cell traffic, and a fall in macro cell traffic. Small cells are more useful in handling

TABLE 1. Comparison of different generations from green communication perspective.

S. No.	Feature	3G	4G	5G
1.	Carbon Dioxide Emissions	86 Mto	170 Mto	235 Mto
2.	No. of BS Sites	3.3millions	7.6millions	11.2millions
3.	Average power consumption per site	1.7kW	1.3kW	1.1kW
4.	BS density	4-5 BS/km^2	8-10 BS/km^2	40-50 BS/km^2
5.	Green Technology Used	High Efficiency Tracking	Green base stations, phantom cells, liquid cells, soft cells	D2D, massive MIMO, spectrum sharing
6.	Carbon footprint per mobile subscription	20kg	23kg	31kg
7.	Femto cell Power Consumption	10W	6W	5W (expected)
8.	RAN Electricity Consumption	49TWh	77TWh	86TWh
9.	Number of antennas at the base station	2	8	Up to 100
10.	Access Technology	WCDMA, CDMA2000	OFDMA, SC-FDMA	BDMA, FBMC
11.	Number of antennas at the SCA	**-**	-	3 antennas at the SCA
12.	Type of antenna used	Clip, high gain and outdoor antenna	Patch and slot antenna	Phased array antennas
13.	OPEX	Low	High	High
14.	SAR Values	High	Higher	Expected to reduce

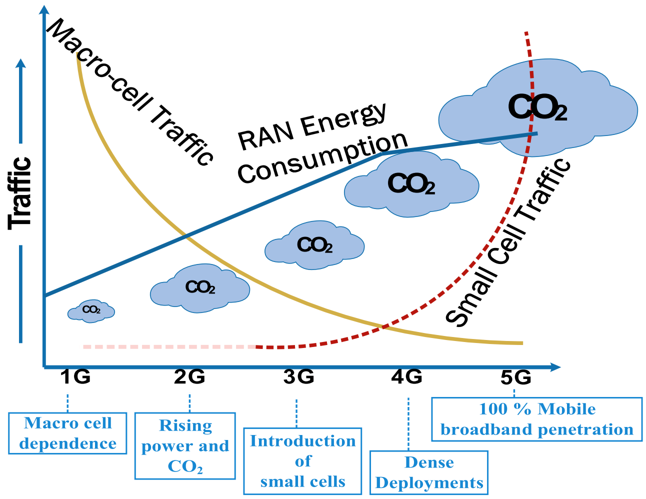

FIGURE 4. Trends in traffic, energy consumption and CO$_2$ emissions, for different generations of wireless communication.

indoor traffic. Service provisioning to such a massive number of users causes a surge in the energy consumption of the radio access network (RAN). Only 15% of the energy is used for the network operation, with the rest 85% not contributing at all to generating the revenue. Clearly, the energy efficiency of the networks needs to be enhanced, for greener next generation networks. A comparison of the wireless generations, for different energy-related features is presented in Table 1, focusing on the need of green communication [9].

The table considers different features, to draw a concrete comparison between the generations of wireless communication. A drastic rise in the CO$_2$ emissions is expected in the next generation networks (5G). This has a direct correspondence with the massive subscriber demands. Since billions of connected devices will be present in the next generation scenario, the total carbon footprint from all mobile phones will reach an alarming rate. To curb such huge emissions, various technologies in 5G networks have come into picture, and are discussed in later section. This section has provided detailed information on the varying trends of the ICT on the global environment. The carbon emissions need to be abated. To start with, power optimization at the base station is discussed.

III. OPTIMIZING POWER AT THE BASE STATION

The use of cellular communication is being largely facilitated. However, cost-efficient communication cannot be provided to remote areas due to deficient infrastructure. To ensure universal coverage, the MNOs and tower companies aim at stretching to extreme remote locations. A substantial growth in the count of off-grid and bad-grid base stations is expected [6], with a region-wise split of additional number of base station deployment presented in Fig. 5, from 2014-2020. A greater amount of deployment will be in the rural area, causing substantial rise in the count of bad-grid BSs. This contributes to the surging CO$_2$ levels in the atmosphere. The off-grid base stations are costlier because of the unavailability of electrical grids.

When a BS is active, its power consumption is given by

$$P_{active} = \frac{\omega B(P_1 + P_{bp})N_{bs} + N_{bs}P_2 + P_{tx/pa}}{(1-\beta_d)(1-\beta_m)} \tag{1}$$

Here, N_{bs} gives the number of antennas at the BS, ω denotes the bandwidth ratio, B gives the bandwidth of the network, P_1, P_2, P_{bp} denote the consumed power of the ADC, filter and other transceiver parts, $\acute{\eta}_{pa}$ denotes the power amplifier efficiency, P_{tx} denotes transmit power of each BS in the network, β_d and β_m denote loss factors of direct current power supply and main supply. This constitutes a significant power level.

As large portion of the energy consumed by cellular networks is drawn from the BSs, it is imperative to improve the

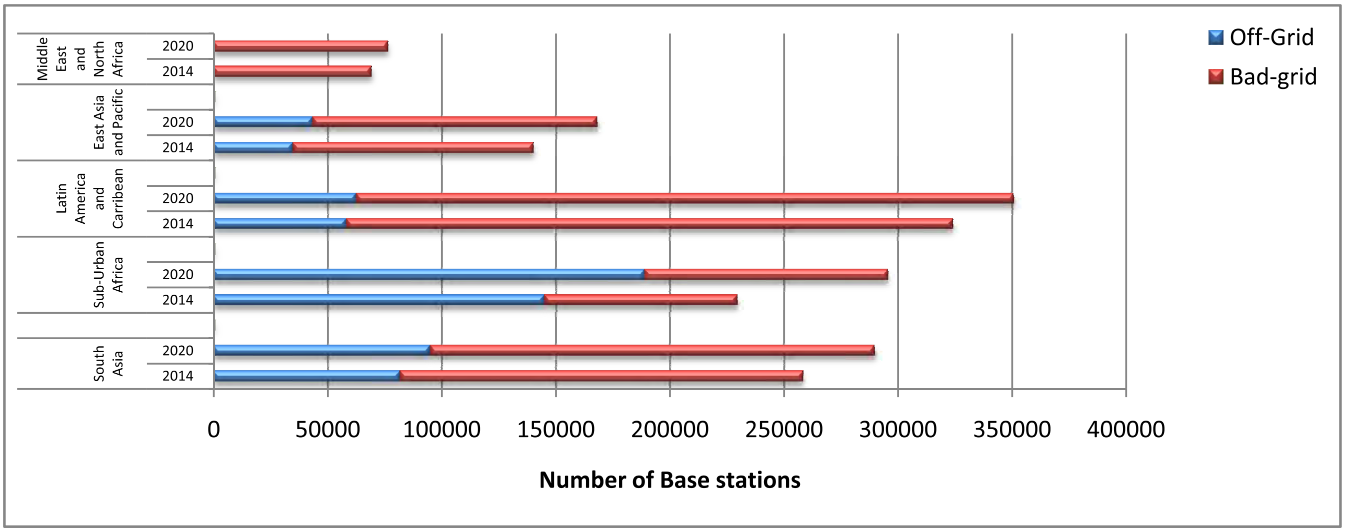

FIGURE 5. Rise in number of base stations from 2014-2020 [6].

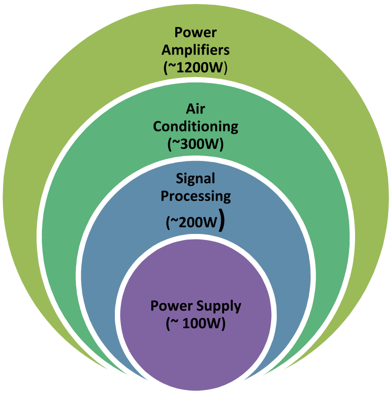

FIGURE 6. Power Consumption by BS components.

energy efficiency of the base stations. Almost 80% of the cellular network energy is consumed by the base station in the network [9]. Within the BS, the power amplifiers and air conditioners always keep working, consuming almost 70% of its energy. The amount of power consumed by each of the components in the base station (BS) is depicted in Fig. 6. A considerable power is consumed by the base station at zero output power as well. Thus, the base station (BS) is the most energy intensive component in a cellular network.

The amount of power consumed at the BS must be scaled to enhance energy efficiency. Various possibilities for efficient power management at the base station are revealed in [35]. Power efficient power amplifiers have also been introduced [36]. The BS hardware, architecture and operation have been evaluated by Mobile VCE. Power saving is further enhanced by deactivation of components when they are not performing any operation [37]. Leakage power can be minimized by gating. Power losses may incur with the main supply, DC-DC power supply and cooling components. These losses scale with the power levels consumed.

A global optimization at the base station is needed, for them to be globally resource optimized and energy efficient (GREEN). Towards the GREEN approach, Niu and Zhisheng [38] proposed TANGO: traffic aware network planning and green operation, which serves as an effective framework for enhancing the energy efficiency of cellular networks and maintain QoS of the networks as well. New base station equipments were installed in 2012, which consumed as much as 50% lesser energy than the earlier base stations. Those which were diesel powered were also now equipped with alternate energy modules like solar batteries. Additionally, cost of transportation of fuel reduces. Green communication technologies have the potential to support three times more traffic, maintaining and ecological and economic balance.

The design of base station is a fundamental in determination of its impact on the environment. Various green base station sites include Tower tube, Capsule Site, Flexi Base Station and others (Table 2). Deployment and use of such sites can result in more than 50% reduction in cost, by sparing the operator's electricity bills and maintenance charges. Green technologies have been introduced by Ericsson, Nokia Siemens Networks, Huawei, Nujira and other companies and have been globally accepted. The BS manufacturers are targeting designs with lower OPEX and CAPEX. For this, use of smart software is being assented at the BS, in conjunction with the green sites. Some of them are listed in Table 3. The new base station designs have a sophisticated layout, consuming large amount of energy, which is referred to as embodied energy. This needs to be taken into account.

The variation in the traffic pattern is typically due to the behavior of the users during the day and night. Traffic during day hours is likely to be much more than during the night hours. Traffic loads remain low during weekends and holidays. Day has a short period, the peak hour, when traffic

TABLE 2. Base station sites for green communication.

Green BS Site	Features
Tower Tube	▪ Co$_2$ emissions reduced up to 30% ▪ Lesser amount of feeder line loss ▪ Introduced by Ericsson ▪ OPEX reduced up to 40% ▪ Lower CAPEX
Capsule Site	▪ Introduced by Ericsson ▪ Highly suitable for installation in urban areas
Flexi Base Station	▪ Introduced by Nokia Siemens Network ▪ Possess ability to be managed remotely ▪ Supports use of renewable energy ▪ Can be upgraded to support new wireless technologies
SDR Soft Base station	▪ Number of elements greatly reduced, resulting in reduced power consumption ▪ Radio frequency unit capable of software programming ▪ Power consumption reduction by 75%
AirScale Base Station	▪ Introduced by Nokia ▪ Single RAN base station ▪ Ability to keep pace with the growing traffic ▪ Supports green communication ▪ Energy efficiency enhancement up to 60% ▪ Low cost
5G New Radio	▪ Introduced by Qualcomm ▪ Ultra low power ▪ Latency up to 1msec ▪ Transmission rate 3Gbps

TABLE 3. Softwares for energy management.

Energy Management Software	Features
NectAct SQM (Networks NetAct Service Quality Manager)	▪ Developed by Nokia Siemens Networks ▪ Suitable for 2G and 3G systems ▪ Allows power saving during variable load on the BS ▪ Has the capability of base station power saving at night
Smart Power Management (SPM)	▪ Developed by Nortel ▪ Suitable for 2G networks ▪ Allows switching off of the BS during no load ▪ Up to 33% power saving can be achieved
Dynamic Power Save	▪ Developed by Alcatel Lucent ▪ Upto 30% power saving can be achieved (Dynamic power save mode) ▪ Suitable for GSM systems (2G)
Standby Mode	▪ Developed by Ericsson ▪ Power saving up to 10-20% can be achieved
Amari OTS	▪ Developed by AmariSoft ▪ Affordable ▪ Suitable for 4G networks ▪ Useful for educational purposes

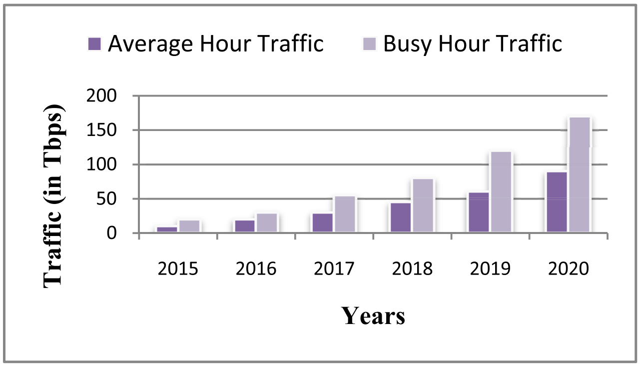

FIGURE 7. Variations in Average and busy traffic hours [188].

is high. Apart from this, traffic patterns are also dependent on the coverage regions, user mobility and nature of applications (video, voice, etc.). Mostly, data, voice and video traffic are bursty in nature, and their dynamicity consumes more energy [39]. Such a trend is expected to continue in the next generation networks as well. The traffic pattern variation from 2015-2020 is depicted in Fig. 7 [188]. The busy hour traffic will soon reach to 702Mbps [40]. Clearly, a tremendous rise in traffic can be witnessed.

The BSs which have load less than a certain threshold, for a specific period of time tend to turn off, i.e. enable sleep mode [41]. When in the sleep mode, the BS has a constant power, denoted by P_{sleep}. Its value depends on the type of sleep mode, i.e. light sleep mode or deep sleep mode [42] (Fig. 8). The power consumed by the BS during sleep mode is 2.4Watt. Thus, average power consumption of BSs deployed

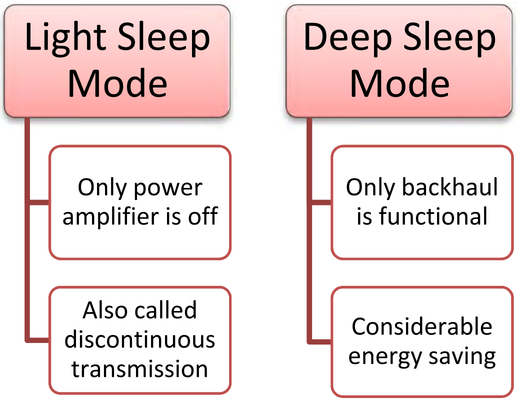

FIGURE 8. Types of Base Station Sleep modes.

over a unit area is given by

$$P_{total} = \rho_{bs}(d_a P_{active} + (1 - d_a))P_{sleep} \tag{2}$$

where ρ_{bs} is the density of BSs following homogeneous Poisson point process (PPPs), d_a is the ratio of the density of active BSs to that of all BSs. The total power is optimized as it plays a key role for obtaining high energy efficiency. The energy consumption can be lowered either through hardware/software modification, or use of base station sleep mode. Cyclic sleep modes are used at the access network [43], [44].

Various techniques incorporating the sleep mode in base stations have been surveyed in [45]. A number of green deployment strategies are available in literature [46]–[48]. These techniques are mostly problem specific. Some of these are not even suitable for the HetNets. In 4G networks, discontinuous transmission (DTX) and discontinuous reception (DRX) can be used for turning off the transceivers when there is no transmission or reception of data [49].

Small cells have been supposed as a sound means of reducing the network energy consumption. Richter *et al.* [50] investigate the power consumption patterns of the network with various deployment strategies. Diverse layouts of micro and macro base stations have been studied and the area power consumption evaluated. Such a technique is capable of improving the energy consumption levels of the overall network. In [51], a static sleep pattern for BSs has been proposed, without taking into consideration the spatial traffic variations, and randomness in the network. Jardosh *et al.* [52] propose a resource on demand (RoD) technique, where a cluster heads are responsible for coverage within a cluster of WLANs, and at low loads, the cluster remains off to save energy. The wake up instants of the base station must also be specified, as it may be required to turn them on, when suddenly the traffic load rises. Under variable traffic intensity, [53], [54] propose adjustment of BS modes (working/sleep), with respect to a blocking probability requirement. Planning and deployment also play a key role [55], and are discussed in Section V.

The work of minimization of the supply power of the base station is proposed in [56]. The authors present a resource allocation using antenna adaptation, power control and sleep modes (RAPS) algorithm for minimum power allocation to resources and spatial channels, deriving the inverse water-filling algorithm. 25% to 40% reduction in power saving is achieved with this algorithm. Using renewable energy powered base stations (green base stations) boost energy efficiency. Coordinated Multipoint transmission [57] can be exploited for enhancing energy efficiency of cellular networks. Via multi-cell cooperation, base stations can be enhanced for greener networks, as discussed in [58]. Another solution can be reduction in BS density within the cellular networks. However, such instances can result in coverage decadence. Cell zooming can also be categorized as a sleep mode.

Due to the explosive rise in the number of subscribers and traffic [39], the concept of cell zooming has come into picture, for green cellular networks, at the network level. Adaptive adjustment of cell size in accordance with the traffic variations is possible with cell zooming, rolling back the network energy consumption. It can be considered as a generalized base station sleeping mode. A cell zooming scenario is depicted in Fig. 9(a), with five cells. The base stations (BSs) are located at the centre of each cell, with the users randomly distributed. If the mobile users move towards the cell at the centre, it results in congestion. To avoid this congested state, the cell shrinks inwards (Fig. 9(b)). Another situation may be that the users move outwards, to the neighboring cells, leading to congestion in them. The central cell can zoom out and the neighboring ones zoom in, to ensure coverage to every user (Fig. 9(c)). For ensuring reduced energy consumption, the cell at the center may move to sleep mode (Fig. 9 (d)). Then the rest of the cells zoom out or function in a cooperative manner to guarantee coverage. Thus, the idea of green networks is safeguarded [59], with focus on the network level performance. Cell zooming is controlled by the cell zooming server (CS).

The effect of cell breathing on electromagnetic radiation levels of mobile phones is studied in [60]. A cell breathing technique is evaluated in [61], which is an efficient one for enhancing the energy efficiency performance of the network. Cell zooming can also be implemented using Coordinated Multipoint transmission (CoMP). These take into consideration the placement of relays at optimal points within the cellular networks [62]. Energy saving gain in cellular networks can be divided into three regions, depending on the traffic patterns, as coverage-limited, energy-efficient, and capacity limited. The coverage-limited region has a light load, and energy saving gain can be achieved in this region. In case of capacity limited region, enhancing network capacity remains the top priority and gain cannot be achieved in this region. BSs and relays remain always on then. A variable energy saving performance is achieved in energy-efficient region.

Cell breathing can also sufficiently reduce interference. The channel conditions and neighboring cells power levels

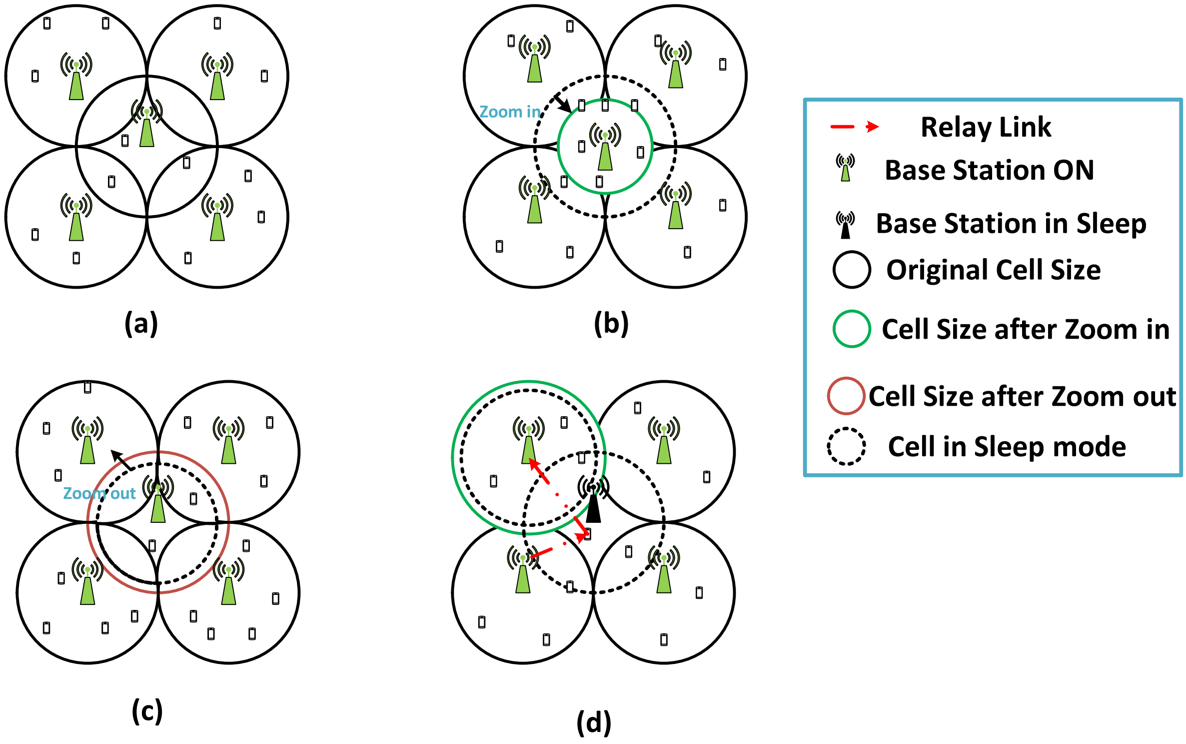

FIGURE 9. Cell Zooming (a) Standard Cell Layout; (b) Cell Zooms in due to high load; (c) Cell Zooms out to ensure service; (d) Sleep mode with information transfer through relaying [59].

must be completely known for cell breathing. For green heterogeneous networks, a cell breathing mechanism, called as path-loss based cell breathing, is proposed in [63], which maximizes energy efficiency with almost negligible degradation. This technique performs better than many other state-of-the-art approaches. Liquid cell management techniques are proposed in [64] and [65] for energy saving and ensuring Quality of Service (QoS) in cellular networks. Thus, the problem of imbalanced traffic and energy consumption of cellular networks can effectively be solved with cell zooming. Till 4G, a critical role has been played by the use of the preceding techniques at the BS. Sleep mode is an efficient technique since no hardware replacement is involved. Thus, these provide a cost efficient technique for green networking. BS sleep modes reduce the OPEX up to 40%. A summary of power optimization at the BS is depicted in Fig. 10. Next, the potential of technologies of 5G networks for enhancing the energy efficiency of the next generation networks has been studied.

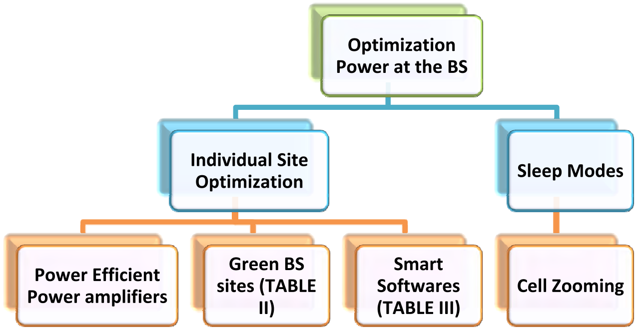

FIGURE 10. Power Optimization at the base station.

IV. POWER ALLOCATION TECHNIQUES AND ENERGY EFFICIENT (GREEN) METRICS

For enhancing the energy efficiency of cellular networks and advancing to green networking, different schemes are used for allocation of power. Two most commonly used power allocation techniques are equal power allocation (EPA) and water filling (WF) algorithm, which have been discussed here. Also, for an energy efficient network design, appropriate performance metrics need to be accurately defined. These are useful for obtaining quantitative information of the network efficiency.

The evaluation of different metrics is essential for a long term research and development, as these allow comparison of performance among different algorithms and proposals. Some important performance metrics for evaluating energy performance of the next generation networks have been discussed here.

A. POWER ALLOCATION STRATEGIES

Enhancing the efficiency of a cellular network is possible with optimal power allocation. It is with the proper power levels that the information can reach the terminals efficiently.

1) EQUAL POWER ALLOCATION (EPA) SCHEME

When a user i, exhibiting total power P_{total} has to transmit using EPA technique, with number of resource blocks N_i, then its transmission power P_i is given by

$$P_i = \frac{P_{total}}{N_i} \tag{3}$$

But, it is not essential that same transmission power is required for each user, and it is expected to largely vary, depending upon the data rate.

2) WATER FILLING ALGORITHM

This scheme for power allocation is used in ISI channels and frequency selective fading channels for maximizing capacity. If an ISI channel is considered, with a gain $|G(f)|$, the maximum data rate achievable, subject to the input power constraint P_i can be obtained from the optimization problem stated as

$$\begin{aligned} &\max \int_0^F \log\left(1 + \frac{|\o_i|^2\,|G(f)|^2}{N_0}\right) df \\ &\text{s.t. } \int_0^F |\o_i|^2 \leq P_i, \\ &\text{and } |\o_i|^2 \geq 0 \end{aligned} \tag{4}$$

where $|\o_i|^2$ denotes the input power spectral density, N_0 denotes the additive white Gaussian noise power, and F is the maximum frequency range.

For satisfying the total power constraint, constant is used, and solution to the above formulated convex problem is stated as

$$|\o_i|^2 = \left(K - \frac{N_0}{|G(f)|^2}\right)^+ \tag{5}$$

This equation is referred to as water-filling power allocation. $\frac{N_0}{|G(f)|^2}$ is considered as the bottom of a bowl, K denoting the level of the water, and $|\o_i|^2$ the water which is filling the bowl.

Water filling power allocation is an iterative power allocation scheme, iteratively allocating power to each sub channel. It is a fast converging algorithm. Loss of spatial multiplexing gain results in a reduction in spectral efficiency [66]. Other techniques for power allocation and optimization include branch and bound (B&B) algorithm [67], game theory, graph theory. These involve lesser computational overhead.

B. THE GREEN METRICS

For a practical system, amount of energy saved and performance needs to be evaluated in a comprehensive manner. Here, energy metrics play a crucial role. These help in determination of the network power consumption as a whole. Energy efficiency metrics can be classified as facility level, equipment level and network level metrics. Energy efficiency metrics have been discussed in [68]. For all the levels, the metrics are defined in a distinct manner. Some of the important green metrics have been discussed below.

1) ENERGY EFFICIENCY (EE)

It is a comparative concept. If the power consumed by the base station is taken into consideration, energy efficiency can be defined as the ratio of total data rate (system capacity) to the total power consumed (b/s/W).

$$\eta_{EE} = \frac{Total\ data\ rate\ (bits/sec)}{Total\ power\ consumption\ (Watt)} \tag{6}$$

2) AREA ENERGY EFFICIENCY (AEE)

When a cellular heterogeneous network is considered, with a dense deployment of small cells (micro, pico, femto), an important performance metric is area energy efficiency. It captures the size of the macro cell on the energy efficiency. It is given as

$$\eta_{AEE} = \frac{Energy\ effciecny\ (bits/sec/Watt)}{macrocell\ area\ (km^2)} \tag{7}$$

3) OUTAGE PROBABILITY

An important metric from the perspective of users in a network is outage probability [69]. It is defined as the probability of a user for which downlink SINR is less than the target SINR, i.e. $SINR_{DL(u)} < SINR_t$.

$$OutageProbablity = P(SINR_{DL(u)} \leq SINR_t) \tag{8}$$

4) SPECTRAL EFFICIENCY

The maximum possible data rate which can be delivered reliably over the channel, with zero error is the channel capacity, $\hat{C}$. With the channel having a bandwidth $\mathcal{B}$, the spectral efficiency in bits per second per hertz is given as

$$\eta_{Se} = \frac{\hat{C}}{\mathcal{B}} \tag{9}$$

Thus, the number of bits received without error is given by the spectral efficiency. Considering an additive white Gaussian channel (AWGN), the spectral efficiency is

$$\eta_{Se} = \log_2\left(1 + \frac{P_{tx}a}{\sigma_0 \mathcal{B}}\right) \tag{10}$$

Here, P_{tx} is the radio transmission power, a is the attenuation power, σ_0 is the noise power spectral density.

5) ENERGY HARVEST RATIO

It is defined as the proportion of time for harvesting energy, within a given slot of time, given as

$$EHR = \frac{T_{EH}}{T_{total}} \tag{11}$$

Here, T_{EH} is the fraction of time during which energy is harvested, and T_{total} is the total time available.

6) AVERAGE SUM RATE (ASR)

It is same as the throughput (number of bits per second). The average sum rate is obtained from the rates of all users within the network. Given the transmission rate over a link as R_{tx}, the

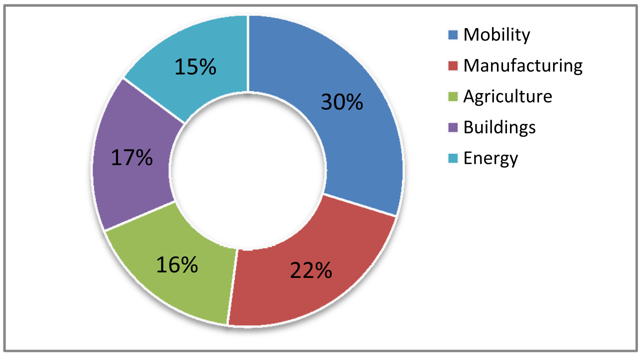

FIGURE 11. Projected Carbon Footprint abatement by 2030, through smart technologies.

average sum rate, for transmission over n number of channels can be given as

$$ASR_{total} = \sum_{k=1}^{n} E\left[R_k\right] \tag{12}$$

A single metric cannot suffice the requirement of green measurement in a cellular network. A combination of these can be useful. Additionally, these can be further extended to include cost aspects. Knowing the power allocation strategies and the metrics for evaluating energy efficiency in cellular networks, the importance of green networking and different technologies are discussed in the next section.

V. 5G ENERGY EFFICIENT TECHNOLOGIES

As already stated, due to the tremendous rise in the number of subscribers and the traffic volumes, power consumption of the networks is rising. The number of connected devices is expected to cross the 50 billion benchmark in the next decade, all of them being connected to the cloud, for anywhere and anytime access to the data. This alarming rise has an adverse impact on the environment. The challenges in correspondence to the rise in the number of devices need to be responded. This is possible through an enhancement in energy efficiency. The designing of the current networks allows capacity enhancement by scaling up the transmission power. However, such escalation is unsustainable from the economic perspective of the MNOs. Different techniques have been adopted for cutting down the network power consumption, like water filling (WF) algorithm [71], equal power allocation (EPA) algorithm [72], [73], game theory, etc.

Network modernization is what is being facilitated by the 5G networks and the networks thereafter. Such networks permit keeping the total power consumption flat. This target is met by minimizing the usage of energy which is not related to information transmission directly. The ICT has the potential of abating 20% of the total CO_2 emissions by 2030 [3]. ICT enabled improvements, expected to abate the CO_2 emissions by 2030 in different sectors is shown in Fig. 11. Various 5G technologies which allow minimization of energy usage are depicted in Fig. 12. The SAR value is also expected to fall in the future 5G networks [74]. The various technologies are discussed in detail in this section.

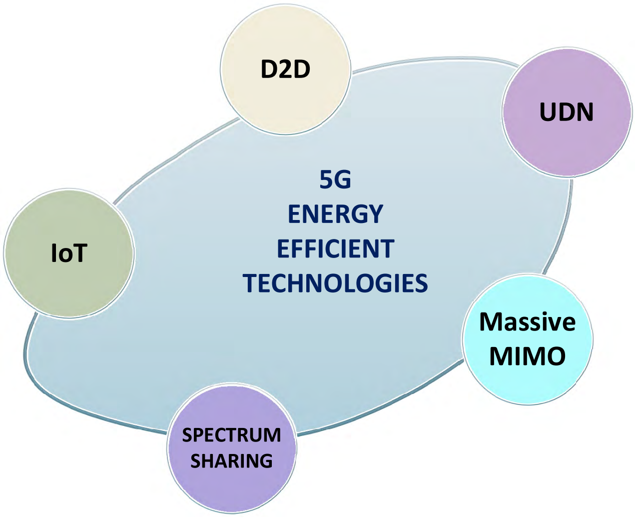

FIGURE 12. Energy Efficient Technologies of 5G Networks.

A. DEVICE-TO-DEVICE (D2D) COMMUNICATION

A competent technology of 5G networks is device-to-device (D2D) communication. It plays a critical role in enhancing the energy efficiency and spectral efficiency [75] of the cellular networks. It boosts the reliability of the link between the users, through direct link formation and latency reduction. Various aspects of D2D communication have been addressed in [76]. Traffic offloading on to the direct links reduces the load on the BS, and works in favor of BS sleeping. Such an approach is useful in saving power at the BS as well as the user equipment. Power control is indispensable in cellular networks, as it is important for interference mitigation among users [77], and enhancing the system capacity. Power control and its optimization with D2D communication are discussed in [78]. A number of techniques for efficient power management have been proposed in literature. Evaluating power control in cellular networks involves use of a number of metrics, of which energy efficiency (EE) is the most common one.

Efforts for energy saving are on the run for wired as well as wireless networks. In case of wireless networks, chief component of energy consumption is the access networks, as these comprise of the major elements, contributing to more than 70% of the total energy consumed [79]. In a communication system, when the users are near cell edges, the base station has to emit extreme levels of power. The power levels may exceed their upper threshold levels, which is highly unsuitable for the cellular networks. For saving system power consumption, D2D communication can be used as an underlay on cellular networks. It serves as an effective technology to cut back ample amount of transmission power.

D2D users can operate in three possible modes: dedicated, reuse and cellular mode. Selection of a proper D2D mode is essential for improved system performance. During a mode selection course, energy efficiency must be given an imperative importance. Feng *et al.* [80] investigate energy-efficient mode switching and solve the EE optimization problem in all the three modes. There is significant improvement in the energy efficiency with the proposed technique, with the reuse mode playing an essential role in the EE maximization for D2D users. Also, successful co-existence of cellular and D2D links require efficient interference management. A joint mode selection and power allocation scheme is proposed in [81]. Power efficiency is defined as the utility function, considering system capacity and transmission power jointly for the maximization of the utility function. First, suboptimal power levels are determined, followed by mode selection. The mode with maximal power efficiency is selected. The simulation results accredit better system capacity with the proposed algorithm, in comparison to conventional schemes. This scheme has an implicit potential for energy efficient D2D communication.

Controlling power levels is a valuable technique of interference mitigation and sustaining coexistence of D2D and cellular communication. In the presence of cellular users, the energy efficiency of D2D users is maximized through a joint power optimization and data rate optimization in [82]. Lagrangian duality theory along with sub-gradient method is applied for obtaining an optimal solution for EE maximization. The algorithm targets achieving proportional fairness among the D2D users and the cellular users.

An imminent progression for the design of 5G networks is green communication, as already discussed. D2D communication, being a surgical technology of these networks, has the ability to maximize the energy efficiency. Zhang *et al.* [83] focus on maximization of EE of the entire network using a derivative-based algorithm. The users are assumed to be randomly distributed over multiple bands, and energy efficiency computed using stochastic geometry theories. The problem is formulated as a non-convex optimization one. This proposed algorithm is very practical and exhibits a low computational complexity. Maximization of energy efficiency is also targeted in [84], through iterative joint resource allocation and power control. A two-layer approach is proposed in which power values are first obtained from a string of maximization problems in layer one. Thereafter, in the second layer, an optimal solution is computed for the formulated problem. The approach is centralized and involves considerable overhead.

In [85], communication between two users is considered to take place through three possible modes: direct D2D, multi-hop D2D or traditional cellular communication. Average energy efficiency and spectral efficiency is analyzed for the three modes. For each mode, the optimal power level of each user equipment is also discussed. Centralized and distributed resource allocation algorithms have been proposed in [86], based on stochastic geometry. A D2D communication underlaying cellular networks is considered for evaluation of the key parameters for obtaining the network performance.

Resource sharing between D2D users and cellular users is possible through three modes: orthogonal, non-orthogonal and cellular. Under the maximum power constraint, power allocation scheme for these three modes are discussed in [87], to escalate energy efficiency. A single cellular user and a pair of D2D users are considered in a single cell, for analysis purpose. Resource allocation is performed by the base station. Optimal power levels are achieved by using non-cooperative game theory for the non-orthogonal mode and quasi-concave function optimization for the other two modes.

A heterogeneous network is considered in [88], with integrated D2D communication and cellular communication for solving a non-convex energy efficiency resource allocation problem. Transformation of non-convex problem to convex one is carried out using fractional programming. Further solutions to the convex problem are achieved by the Dinkelbach and the Coordinate Ascent Methods. Coexistence of D2D communication with cellular networks resulted in a higher energy efficiency, as reflected in the simulation results.

Ali *et al.* [89] formulate the energy efficiency maximization problem in connection with resource allocation and selection of cells in case of Heterogeneous networks (HetNets). Charnes cooper transformation is used for the solution formulation as an Outer approximation algorithm (OAA). Subject to minimum data rate constraints, optimal power allocation in HetNets is considered and extensively evaluated to get to an ε-optimal solution. The proposed algorithm is a linearly converging algorithm.

For D2D communication underlaying cellular networks, an energy-efficient power control scheme is proposed in [90]. The EE is considered as an objective function, and the minimum data rate constraints are also considered for guaranteeing the QoS thresholds of the network. Individual EE and total EE, both are formulated as non-concave fractional programming and generalized fractional programming problems, respectively. This scheme is a centralized one, having lesser amount of associated complexity and computational overhead. EE performance is evaluated for optimal and sub-optimal schemes, and it is observed that the performance of both is quite close to each other.

Xiao *et al.* [91] propose an efficient power optimization scheme for significant saving of the overall power consumed by the base station. An OFDMA system is considered for subcarrier and bit allocation, along with proper mode selection to integrate D2D communication. The downlink power is optimized comprehensively for network with a fair amount of D2D pairs. As already stated, interference between cellular and D2D users can be coordinated by proper power control. Prioritization of cellular and D2D users can also be performed by controlling power. In [92], under maximum transmit power constraint; greedy sum rate maximization is performed. Firstly, cellular users are prioritized under the maximum power constraint, with a guaranteed minimum transmission rate. Then, an upper limit of the transmission rate is set for a practical system, constrained by the highest modulation and coding scheme. Thus, the users remain rate constrained then. Orthogonal and non-orthogonal resource sharing is considered between D2D and cellular users, where the optimal decision on the mode selection is made by the BS. With prioritized cellular communication, power control is confronted; overcoming interference and achieving enhanced sum rates.

An energy efficient power control design has been investigated in [93], by formulating a multi objective optimization problem (MOOP) for maximization of energy efficiency. Energy efficient resource allocation and mode selection are discussed in [94].

D2D communication is efficient in handling the tele-traffic, using adhoc networking technology. However, the devices are battery powered, and remain idle after depletion of their batteries. To prolong the device lifetime, energy harvesting [95], [96] at the devices is needed. Gupta *et al.* [97] propose a sum-rate maximization problem for optimizing the matching between cellular and D2D users, along with allocation of power to the D2D links. The energy harvesting (EH) constraints and QoS constraints are taken into consideration, for a network with D2D transmitters capable of harvesting energy from the environment.

Cognitive and energy harvesting based D2D communication is analyzed in [98]. The authors intend harvesting capability of D2D transmitters. Concurrent transmissions during uplink and downlink generate interference from which energy can be harvested. After harvesting is complete and the D2D transmitters have sufficient energy harvested, they perform spectrum sensing, considering two policies for spectrum access (random spectrum access and prioritized spectrum access). The proposed system is evaluated using stochastic geometry. Since the energy harvesting circuitry is available at each D2D transmitter, capable of harvesting RF power from uplink and downlink channels, the total power that can be harvested by the transmitter is given as

$$\begin{aligned} P_{D2D}(y) &= \text{ß}\sum\nolimits_{C\in C_{DL}}\sum\nolimits_{y(i)\in \text{Ø}_{BS(C_{DL})}} P_{BS}h_{y(i)}\|y_{(i)}-X\|^{-\alpha} \\ &\quad +\text{ß}\sum\nolimits_{C\in C_{UL}}\sum\nolimits_{z(i)\in \text{Ø}_{CU(UL)}} P_{UL}h_{UL(i)}\|z(i)-X\|^{-\alpha} \end{aligned} \tag{13}$$

Here, α denotes the path loss exponent, c gives the set of channels (C_{DL} denote the downlink channels and C_{UL} denote the uplink channels). y(i) model the location of macro BSs by homogeneous PPP, '$\text{Ø}_{BS(C_{DL})}$' representing the set of BSs using downlink channels and z(i) model the homogeneous PPP distribution of cellular users, $\text{Ø}_{CU(UL)}$ denoting set of users using uplink channels. X denotes a generic location in the given space. Since D2D transmitters harvest the RF energy, ß gives the efficiency of conversion from RF to DC. P_{BS}, P_{UL} denote downlink power level of the base station and uplink power level of cellular user, respectively. Thus, in the above equation, RF power harvested from concurrent downlink cellular transmissions is given by the first term and from the uplink is denoted by the second term. The performance of both types of users within the system (D2D as well as cellular) is quantified with regard to the transmission probability of D2D users. This proposal provides an acceptable QoS level with cognitive D2D communication.

For enhancing the link quality, transmission through relays has been proposed by 3GPP [99]. Relays used, may be fixed (Type I) or mobile (Type II). However, extra power is needed for the relay, to carry out the transmission. The role of energy harvesting in such a scenario plays a crucial role. EH has a certain degree of randomness associated with its power profile, which should be given consideration in such networks. In [100], a heterogeneous network capable of energy harvesting is considered, along with support for D2D communication. The relays are considered to possess EH and can forward information to D2D users utilizing the harvested energy. The energy harvested by each UE is modeled by Markov chain. Such an exploitation of harvested energy in D2D communication can improve the network performance through efficient energy utilization. A considerable amount of energy can be saved using the proposed mode selection technique. Thus, D2D can effective support the schema of green communication, along with BS sleeping and the following technologies, discussed in the further sections. A network model gives a brief overview of the computation of energy efficiency and its modeling through suitable mathematical equations in a cellular network, with D2D users underlaying cellular communication.

1) NETWORK MODEL

A D2D network underlaying cellular networks is considered in a single cell scenario (Fig. 13). A random distribution of cellular and D2D users is considered, where uplink cellular resources are shared by the D2D users. Let 'N_c' number of cellular users, 'R' number of resource blocks (RBs) and 'L_d' number of D2D pairs be taken into consideration, for the single cell scenario. The entities must follow the relation $L_d \leq N_c = R$. A single RB corresponds to one time slot and twelve subcarriers. Allocation of RBs to cellular users is considered to be already performed. From j^{th} cellular user, average received power at the BS is given by

$$P_{BS,j} = \text{Ꝁ}\, P_{j,k}(D_{j,BS})^{-\tilde{\alpha}} \tag{14}$$

where Ꝁ denotes the path loss constant, $\tilde{\alpha}$ denotes the path loss exponent, $P_{j,k}$ denotes the transmit power of j^{th} cellular user on k^{th} RB and $D_{j,BS}$ denotes distance between the BS and j^{th} cellular user.

If k^{th} RB of j^{th} cellular user is reused by i^{th} D2D pair, transmission power of i^{th} transmitter of the D2D pair is denoted as $P_{i,k}$. The corresponding data rate of i^{th} pair is given by

$$\underline{R}_{i,k} = \acute{w}log_2(1 + \frac{P_{i,k}h_d^{(i)}}{P_{BS,j}h_{j,i} + \dot{N}_0}) \tag{15}$$

Here, $\acute{w}$ denotes the RB bandwidth, $h_d^{(i)}$ denotes channel gain between the D2D transmitter and receiver, $h_{j,i}$ denotes the interference gain of the channel between j^{th} CUE and i^{th} pair's receiver, and $\dot{N}_0$ denotes the noise power. For

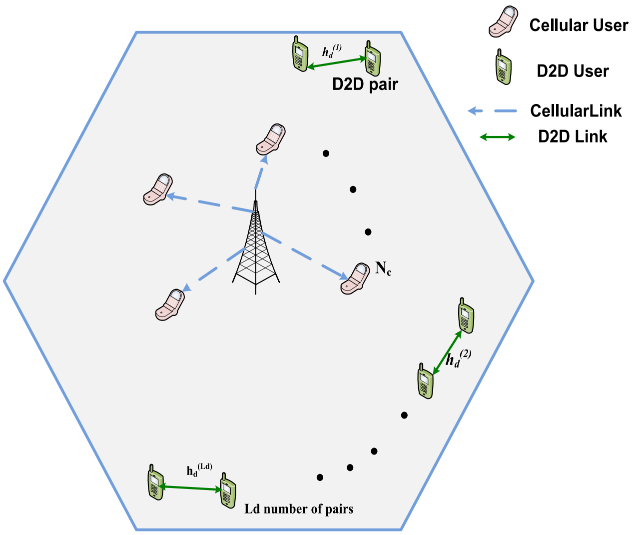

FIGURE 13. Network Model for Single Cell scenario.

TABLE 4. Symbols of network model.

Symbol	Meaning
N_c	Number of cellular users
R	Number of resource blocks
L_d	Number of D2D pairs
$P_{BS,j}$	Average received power at the BS from jth cellular user
₭	Path loss constant
$\tilde{\alpha}$	Path Loss Exponent
$P_{j,k}$	Transmit power of j^{th} cellular user on k^{th} resource block
$D_{j,BS}$	Distance between BS and j^{th} cellular user.
$\underline{R}_{i,k}$	Data rate of i^{th} pair reusing k^{th} resource block
$\acute{w}$	Bandwidth of resource block
$P_{i,k}$	Transmission power of i^{th} transmitter of the D2D pair
$h_d^{(i)}$	Channel gain between the D2D transmitter and receiver
$h_{j,i}$	Interference gain of the channel between j^{th} CUE and i^{th} pair's receiver
$\dot{N}_0$	Noise Power
P_{ckt}	Total circuit power consumption for all pairs
P_{static}	Static power
ζ	Constant giving the dynamic power consumption per unit throughput
$x_{i,k}$	Indicator of whether k^{th} RB is allocated to i^{th} pair or not
R_{min}	Minimum data rate requirement
EE_{d2d}	Energy efficiency

maintaining the QoS requirements of every user within the network, a minimum data rate constraint exists. Taking the minimum data rate constraint as R_{min}, the necessary condition for maintaining the QoS of the network is

$$\underline{R}_{i,k} \geq R_{min} \tag{16}$$

Energy efficiency is used as an optimization objective to meet the goal of green communication. This supports transmission of more number of bits per unit joule, under the constraint of minimum data rate. The energy efficiency of D2D communication is defined by the total data rate to the total power consumption in the networks, and given by

$$EE_{d2d} = \frac{\sum_{i=1}^{L_d} \sum_{k=1}^{R} \underline{R}_{i,k} x_{i,k}}{\sum_{i=1}^{L_d} \sum_{k=1}^{R} x_{i,k} P_{i,k} + P_{ckt}} \tag{17}$$

P_{ckt} is the total circuit power consumption for all pairs in the network. It is a combination of a static and a dynamic term. $x_{i,k}$ is an indicator of whether k^{th} RB is allocated to i^{th} pair (value equals one) or not (value equals zero).

For i^{th} pair, the circuit power is given as

$$P_{ckt} = P_{static} + \zeta R_{i,k} \tag{18}$$

where P_{static} denotes static term and ζ denotes a constant giving the dynamic power consumption per unit throughput. The target remains energy efficiency maximization, i.e.

$$\max EE_{d2d} \tag{19}$$

In order to maximize the energy efficiency, the total power consumption must be minimized. Thus, EE can be maximized, subject to minimization of

$$\sum_{i=1}^{L_d} \sum_{k=1}^{R} x_{i,k} P_{i,k} \leftarrow minimum \tag{20}$$

Channel conditions play a key role in the entire analysis, for minimization of transmission power. The system energy efficiency is profoundly affected by D2D communication, since information transmission between devices occurs at very low transmit power levels. Also, D2D communication supports offloading mechanism, thereby lowering load on the BS and saving considerable amount of energy. The various symbols used are given in Table 4.

B. ULTRA DENSE NETWORKS

For the provision of abundant wireless connectivity, new technologies are building up. Seamless connectivity is ensured with the development of UDNs. These provide an essential platform for the paradigm shift, in the NGNs. UDNs involve dense small cell deployment, in areas with enormous traffic. Small cells are low power, low cost wireless access points which provide improved coverage and capacity, with data offloading [101]. Micro, pico and femto cells are deployed for improving indoor coverage. Enhancing coverage with small cell deployment has brought about considerable improvement in the spectral efficiency and energy efficiency of the cellular networks. The varying cell size and their respective transmission powers is shown in Fig. 14. A distributed architecture for UDNs in 5G has been proposed in [102]. A comprehensive survey on UDNs has been presented in [103]. Various proposed schemes for energy efficient UDNs have been overviewed in literature.

A key solution for embracing the high data rate demands of the cellular networks can be effectively met by femto cells. Dense deployment of such cells results in excessive energy consumption, requiring boosting of network EE. A clustering

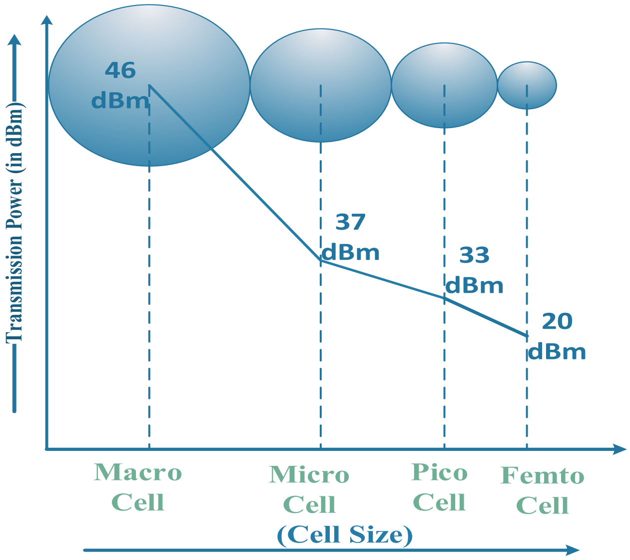

FIGURE 14. Cell size v/s transmission powers.

approach to achieve the goal is proposed in [104]. Simple algorithms are designed for the semi-centralized framework. The proposed scheme is highly computationally efficient, with reduced levels of complexity.

Maximizing energy efficiency in UDNs has been proposed in [105], with the use of stochastic geometry. For traditional cellular networks, integrating pico cells has been an eminent solution for capacity and coverage enhancement, involving low cost and low power. But, dense deployment of pico cell BSs cause excess energy consumption. Obaid *et al.* [106] analyze energy efficiency and area energy efficiency, considering power levels of macro and pico base stations. For a base station, the total power consists of two parts: static (consumed by BS operation) and dynamic (dependent upon load on the cell). The power levels of a macro BS and pico cell (in case of ultra dense deployment) are given by the following equations:

$$P_{M_{BS(i)}} = n_s n_t \left(\rho_M P_M^{total} + P_{aM}\right) \tag{21}$$

$$P_{p_{(i)}} = \rho_p P_p^{total} + P_{aP} \tag{22}$$

Here, n_s and n_t denote the number of sectors and number of antennas, respectively; ρ_M and $\rho_p$denote the power consumption coefficients and P_{aM} and P_{aP} denote the fixed powers of the macro BS and pico BS, respectively, consumed by the auxiliary equipment. P_M^{total} and P_p^{total} are total macro BS power and total pico BS power. The power levels at the macro BSs are optimized, along with sum rate maximization of picocells. Optimizing downlink power of macro BS results in enhanced EE, as is depicted by the simulation results.

As per the ongoing scenario, network densification will reach unabridged levels with the deployment of ultra dense networks. Yunas *et al.* [107] analyze energy efficiency of the network for different indoor and outdoor deployment scenarios. Extreme levels of densification have been evaluated. The simulation results show high energy efficiency of densely deployed indoor scenarios, in comparison to outdoor ones. Such an approach is useful for practical systems, in terms of cost and energy efficiency.

For green ultra dense networks of the next generation, critical performance parameters shall be spectrum efficiency, energy efficiency and cost efficiency. All these metrics are mathematically modeled in [108], into a single unified mathematical model. A weighted utility function is designed, followed by Nash product utility function, taking all the three efficiencies into consideration. Optimal equilibrium solutions can be achieved with the proposed design. A technique for improving spectral efficiency and EE, which supports BS sleep mode during no traffic periods is investigated in [109].

Sharing of same spectral resources between small cells and macrocells results in interference. A utility function based on SE and EE has been formulated in [110] for interference mitigation and saving energy, collectively. Then cooperative relay with spectrum leasing and cooperative capacity offload are proposed for performance evaluation. A tradeoff between SE and EE is achieved with the proposed model, and verified by the simulation results.

For optimizing energy efficiency in UDNs, a novel approach has been proposed in [111] for joint power control and user scheduling. The problem of interference within the densely deployed network is modeled as a dynamic stochastic game, which is further casted as a mean-field game. The user scheduling is formulated as a stochastic optimization problem. It is then solved by a drift plus penalty approach. The proposed scheme is efficient in assuring QoS to the users within the network, with remarkably improved EE.

For dimensioning of cellular networks, frequency reuse factor is a key parameter. Most of the existing literature in connection to BS deployment considers universal frequency reuse, causing degradation of SE and EE due to inter-cell interference. A random deployment of BSs is considered in [112] for optimizing frequency reuse factor, forming a dense deployment.

The gap between the amount of resource supply and the demand is filled by cell breathing. Details on cell breathing have been discussed earlier. For improving the energy efficiency of UDNs, a high resolution cell breathing (HiRCB) technique has been proposed in [113]. Spatial and temporal variations in traffic have been considered. At least 50% energy efficiency is improved, with the proposed technique.

For wireless charging of devices, a promising technique under consideration is energy harvesting from RF sources. Energy harvesting can be ambient energy harvesting or dedicated energy harvesting. Recent advances in this field and the linked shortcomings have been discussed in [114], helping the researchers to identify the research gaps. Feasibility of energy harvesting in ultra dense networks has been evaluated by the authors. The proposed technique is capable of optimizing network parameters, for UDNs. A precoding scheme for enhancing energy efficiency of small cell networks is proposed in [115]. EE of the system is optimized by formulating the cell association and power allocation problem. Sleep mode is available for the small cell base stations

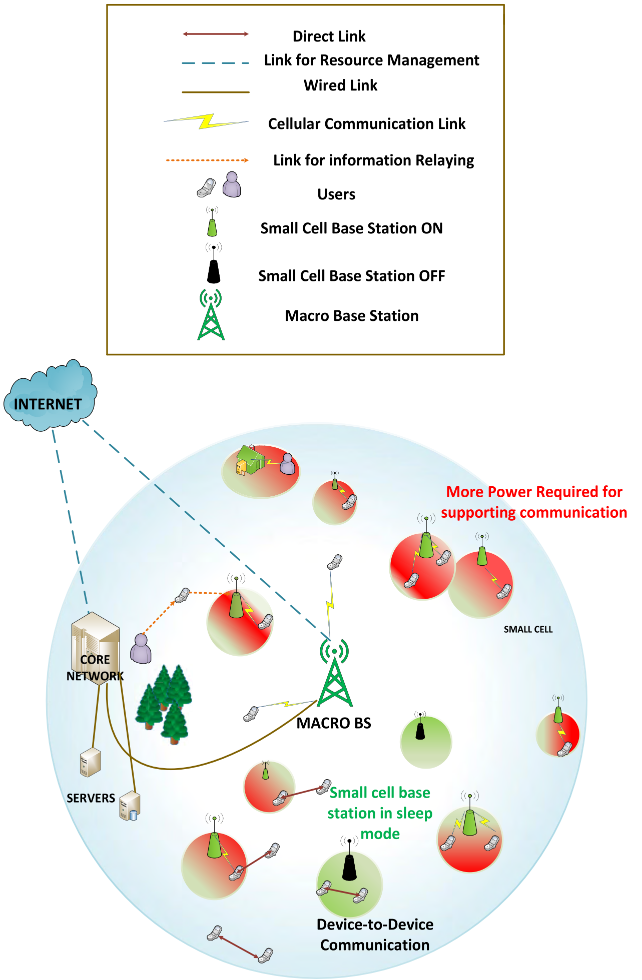

FIGURE 15. **Power distribution in small cell arrangements for Ultra Dense Deployments.**

to avoid energy wastage. The network energy consumption is greatly reduced, along with significant reduction in cost of the network as well. A UDN scenario is depicted in Fig. 15., where dark red regions depict greater amount of power required by the base station, and lighter red shade indicates lesser amount of power. Use of Massive MIMO further enhances the network performance. From the various algorithms studied so for, for enhancing energy efficiency with UDNs, [105], [107]–[109] have been considered for comparison of their energy efficiencies, with the base station density of 100 per km^2. The variations in energy efficiency have been shown in Fig. 16.

Introduction of small cells engender a number of opportunities, along with some challenges. The deployment of small cells in excess has led to a number of adverse effects on the network as well as the backhaul. Deployment of small cells in excess has an adverse effect on the energy efficiency of the cellular networks. The small cells function at very low power levels in comparison to the macro cell. But, if these are deployed in an unplanned manner, and unnecessarily in abundance, they can cause huge amounts of energy wastage. The mobile terminals may drain out of battery due to unplanned deployment. Major portion of the energy is utilized for provision of coverage. As a result, no cooling is needed in small cell deployed networks, optimizing the power budget. With increasing number of small cell base stations, the EE first increases and then decreases. Thus, there is a limit on the number of small cell base stations. A number of agile technologies are being worked upon, to overcome these critical aspects.

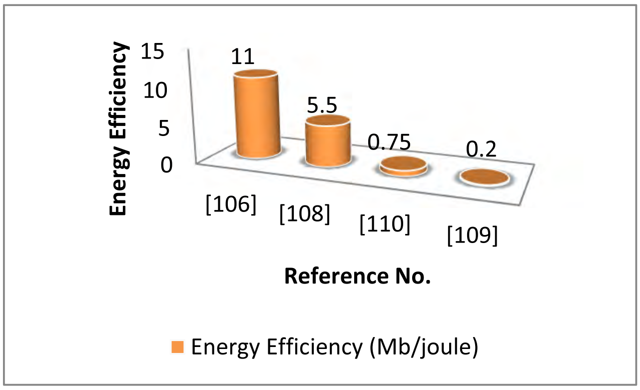

FIGURE 16. **Comparison of different UDN energy efficient techniques.**

C. MASSIVE MIMO

Multiple Input Multiple Output (MIMO) has played a critical role in the 4G networks. Up to eight antenna ports have been allowed at the BS, using MIMO. This technology continues to the NGNs, supporting hundreds of antennas and providing data rates of several gigabits per sec (Gbps) [116]–[119]. It is massive MIMO. This evolving technology offers a number of advantages. It can be stated that it provides all benefits of MIMO, but on a larger scale. Difference between MIMO and Massive MIMO are depicted in Table 5. Massive MIMO offers a number of advantages, including enhanced throughput, reduced latency, robustness against jamming, improved spectrum efficiency, huge capacity gains and enhanced energy efficiency (EE) [120]. For N_T number of antennas at the base station, the transmission power of the BS varies inversely with the number of antennas for perfect channel state information (CSI), and varies inversely as $\sqrt{N_T}$ for imperfect CSI known. Massive MIMO is more energy efficient than MIMO [121]. Radiated power can be reduced up to 1000 times with Massive MIMO [122].

Massive MIMO is a technology enabler for overcoming the capacity crunch in the next generation mobile networks. Integration of antenna arrays to the next generation networks has been indicated in [123]. It also investigates three massive MIMO deployment strategies: single massive MIMO, distributed massive MIMO and network massive MIMO. Use of multiple antennas brings about enhanced degree of freedom (DoF) and thus, acts as a booster for physical layer performance.

A simple multi-cell massive MIMO network is shown in Fig. 17. A multi-cell massive MIMO system is considered

TABLE 5. Difference between MIMO and massive MIMO.

MIMO	Massive MIMO
Constant circuit power consumption	Circuit power consumption is not constant due to the use of extensive circuitry
Up to eight antennas used at the base station	Hundreds of antennas can be used at the base station
3GPP Release 11	3GPP Release 13
Operates in FDD and TDD	Mostly TDD operation; can support FDD also
Improved throughput, but less than massive MIMO	Large scale improvement in throughput
Involves use of simple channel models, like Knonecker	Sophisticated channel models used
Improved EE	EE improvement of the order of 100 times
Supports improvement in SE	SE improvement is 10 times than conventional MIMO
Cannot prevent jamming	Highly robust to jamming
No problem of pilot contamination	Has the problem of pilot contamination
Supports large degree of freedom	Supports much larger degree of spatial freedom

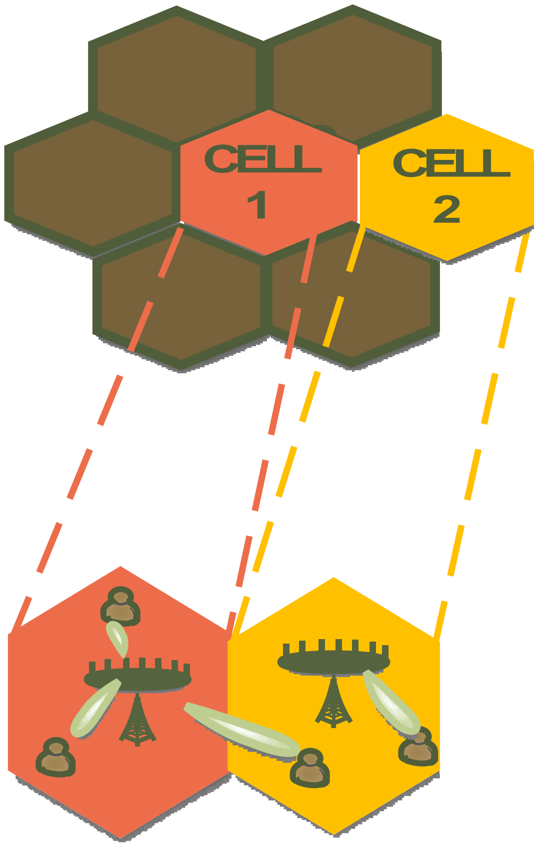

FIGURE 17. A massive MIMO Scenario, with multiple cells.

in [124], with the target of reducing the total power consumption. The transmission power in minimized by considering the spectral efficiency constraints at the user equipments (UEs) and the power budget constraints at the base station. The effectiveness of the proposed scheme is validated by simulation results.

Another multi-cell massive MIMO network is analyzed in [125]. Scaling laws of energy efficiency are investigated with maximum ratio transmission (MRT) and zero-forcing beamforming (ZFBF). Transmit power, circuit power, channel estimation errors and pilot contamination are taken into consideration and the energy efficiency is maximized subject to minimum data rate requirement, along with maximum transmission power constraints. In the procedure of determination of scaling laws, pilot contamination (PC) plays a dominant role. The analysis is validated for realistic channel models by simulation. When more energy budget is available, power allocation to the pilot signals should be more for spectral efficiency maximization [126].

The overall energy utilization within the system is optimized in [127], considering single-cell and multi-cell scenarios for a massive MIMO network. An alternative optimization plus bisection searching (AO-BS) algorithm is proposed for optimizing length pilot sequences and determining the optimal parameter setting for energy efficient massive MIMO. The problem under consideration is divided into a number of sub problems and each of them are solved using AO-BS. Pilot contamination (PC) is extensively studied for optimal parameter selection. Simulation results prove fast convergence of the proposed algorithm.

For maximization of system energy efficiency, joint pilot assignment and resource allocation is studied in [128]. Pilot contamination is considered explicitly for power optimization. For a convex optimization problem, a successive convex optimization technique is used. A much better performance can be achieved through the proposed scheme, in respect of system energy efficiency and sum rate.

In the next generation networks, short range communication is gaining recognition. In a device-to-device (D2D) communication network, reusing downlink cellular resources, energy efficiency has been studied for multiple number of antennas at the base station in [129]. The proposed scheme targets improvement in the energy efficiency and average sum rate (ASR) for varying densities of D2D users (DUEs) in the system and multiple antennas at the base station.

Though there is an increasing attention towards ultra-dense deployments, their powering and backhauling remains a prime concern. Deployment of large number of small cells results in increase in the power consumption levels of the small cell base stations (SBSs), and increased amount of fiber required for backhauling, causing increased cost. Meeting the Quality of Service (QoS) and reducing CaPex and OPex is essential. Chen *et al.* [115] perform self-backhauling and energy harvesting jointly, to tackle this concern. The use of full duplex (FD) technology enhances spectral efficiency and energy efficiency with the proposed scheme. A precoding scheme is used to mitigate inter-tier and multi-tier interference within in the system. It is a highly converging algorithm and effective in improving the system energy efficiency, spectral efficiency and energy consumption, as depicted by the simulation results.

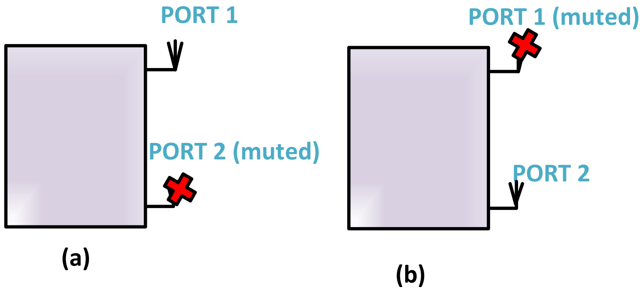

FIGURE 18. Antenna Muting.

A distributed power control algorithm is proposed in [130]. A multi-cell, multi-user scenario is considered, where each user has the ability to optimize its energy efficiency (EE). This reduced the computational complexity drastically. Evolutionary game theory (EGT) [131] is used which improve fairness among users in the network.

In order to achieve a balance between spectral efficiency and bit error rate, antenna grouping is required. Antenna grouping beamforming is proposed in [132]. Jiang *et al.* [133] investigate antenna grouping and antenna selection using beamforming and spatial multiplexing to improve EE of a multi-user massive MIMO system. The optimal number of transmit antennas are investigated using a low complexity binary search algorithm, thereby enhancing EE.

Due to the large number of antennas at the base station, complexity problems may arise. These remain an open area to be addressed by the researchers. Another energy efficient technique in relation to antennas is antenna muting, as explained in the next section.

1) ANTENNA MUTING

Activating all the antennas is not an energy-efficient choice. A subset of the antennas available is antenna selection, which improves the performance of MIMO systems [134]. The energy consumption within a cell can be reduced by antenna muting. Up to 50% energy can be abridged for scenarios with low load or no load, without disturbing the user throughput. In case of antenna muting, if an antenna possesses two or more ports, all ports can be turned off during no load or light load conditions and only one of them kept on, without any significant effect on the overall network operation. As an illustration, an antenna with two ports is shown in Fig. 18, depicting working of antenna muting. It is a solution introduced in EARTH for reducing energy consumption. The user is not affected by such an arrangement. Reducing energy consumption in LTE networks with antenna muting is discussed in [135]. Integration of a three-sector site (psi-omni reconfiguration) with antenna muting can enhance user performance and energy consumption [136]. Almost 43.8% consumed energy is reduced with the proposed technique.

A self-optimizing antenna muting scheme is evaluated in [137], using a dynamic simulator where radio units get activated adaptively and remain deactivated during low load conditions. Node topology and beam width determine the interference between nodes. The beamwidth can be controlled by antenna muting, which adjusts active antenna elements on the basis of distance of the links. Using a probability approach, the network power consumption is minimized in [138]. Relation between antenna arrays and spatial reuse gain is analyzed, bringing about an energy saving of up to 80%. During the phases of antenna muting within the network, energy efficiency degradation may also occur [139]. Thus, this scheme must be used with caution, so that the overall network performance does not degrade. Clearly, massive MIMO provides a unique platform for optimizing the power levels in a cellular network.

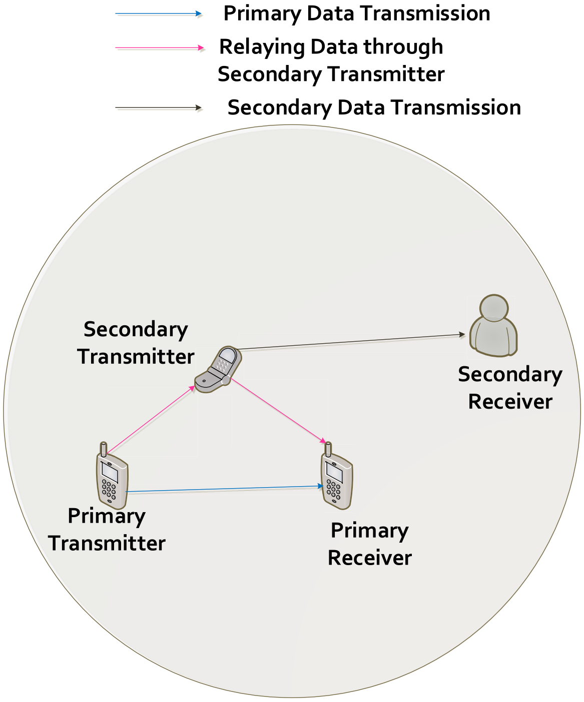

FIGURE 19. A general Spectrum Sharing Scenario.

D. SPECTRUM SHARING

Dedicated licensed spectrums are available for the cellular networks to operate. Additionally, there is unlicensed spectrum and different shared licensed spectrums for wireless communication. The radio spectrum is facing acute crowding, necessitating dynamic spectrum allocation. With the rise in dense deployments, there is a need for regulatory options for 5G and beyond, to avoid low spectrum utilization efficiency [140]. For ensuring coverage all the time and everywhere, the notion of spectrum sharing has been anticipated. A general spectrum sharing scenario has been shown in Fig. 19., with a single primary transmitter, primary receiver, secondary transmitter and a secondary receiver. The primary transmitter and receiver communicate directly, or through the secondary transmitter. It allows secondary users to access the unutilized/underutilized parts of the spectrum through different sharing strategies (underlay/overlay/mixed). It is an effective technology for

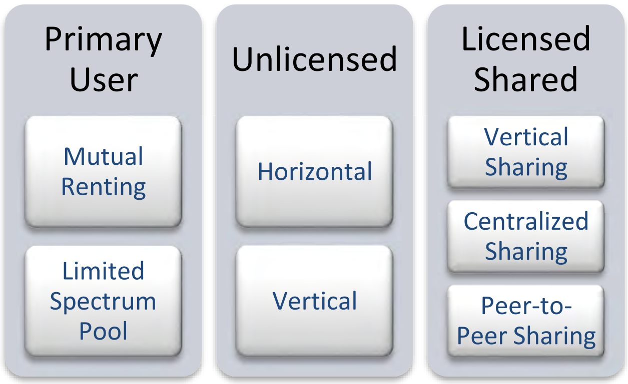

FIGURE 20. Possible Modes of operation in Spectrum Sharing.

simultaneous energy efficiency maximization and spectral efficiency management [141].

Spectrum may be shared orthogonally or non-orthogonally [142], [143]. Various advanced scenarios for spectrum sharing and modes of operation (Fig. 20) have been discussed in [144], along with the enabling technologies. Techniques for spectrum sharing can be broadly categorized as distributed and centralized [144]. Spectrum sharing systems on a hardware deployment have been studied in [145], adhering to the regulatory constraints for the users. It is an efficient means to solve the problem of rising user demands. Developments in some recent circuit optimization techniques have been discussed in [146], considering power efficiency and spectral performance. Such systems target flexible spectrum usage, to achieve high capacity. Optimizing power levels in spectrum sharing networks has been studied in literature.

For a limited set of operators possessing similar spectrum access rights, spectrum sharing is considered in [147], and a coordination protocol designed at the radio access network (RAN) level. It requires a peer-to-peer connection between operators and decision rules to determine the sharing outcome. It has a low computational complexity, does not involve excess information exchange among operators, and is adaptive to interference among operators and load variations. It involves the use of non-monetized spectrum sharing.

For primary users subject to fragile channel conditions, a full duplex (FD) opportunistic protocol for spectrum sharing has been proposed in [148]. The primary signals are forwarded by the secondary users, acting as decode and forward (DF) relays, using a set of subcarriers. The primary system can then achieve their target data rates, upon allocation of subcarriers by the secondary system. Another set of subcarriers are used by the secondary users to transmit their own signal. Such a protocol is particularly important when weak channel conditions are experienced by the primary user. Such a scheme is beneficial to both primary and secondary system as it avoids interference between the two types of users.

For improving the efficiency of spectrum sharing, cooperation is a key technology. Cooperative spectrum sharing is studied in [149], using stochastic geometry. Gao *et al.* [150] propose best cooperation mechanism (BCM), which is capable of harvesting energy as well as transmit data within a timeslot, in a network with multiple primary users. In this scheme, the secondary users can cooperate with the other secondary users and primary users, with both the type of users capable of harvesting energy. During data transmission by the primary user, the secondary users are capable of acting as relays, which supports throughput enhancement and accelerates data transmission rate of the primary users. When secondary users act as relays, transmission of the primary users is complete well before time. The formulated optimization problem is solved using cat swarm optimization (CSO) [151]. The superiority of the proposed algorithm has been verified through simulation results.

For a two-tier heterogeneous network (HetNet), spectral efficiency and energy efficiency have been analyzed in [152] under a spectrum shared scenario. The need for a practical approach for multi-tier cellular networks has been given a prime importance in the proposed scheme. Karush-Kuhn-Tucker (KKT) conditions are used for determination of an efficient operational regime. It has been analyzed that increasing density of femto-tier BSs results in higher SE **and** EE, but rolls off with increasing BS power consumption and the rising load.

Spectrum sharing based on OFDM has been discussed in [153] and [154]. The concept of time averaging window in spectrum sharing networks has been studied in [155], to study the downlink radio resource allocation (RRA) problem in a multi-carrier network. Optimal resource allocation is performed using dual decomposition method. Practically implementable online power and subcarrier allocation scheme is also evaluated, based on channel state information measurement. The algorithm is a fast converging one, using KKT conditions for optimal power allocation.

An efficient technique for improving spectrum efficiency as well as energy efficiency is partial spectrum reuse [156]. It is effective in avoiding intercell interference in heterogeneous networks (HetNet). In [157], β-PSR (partial spectrum reuse) scheme is proposed where, in a HetNet, macro BSs can access the entire spectrum while the micro BSs can access only a part of the spectrum, β, which is random and independently generated. Dynamic BS sleeping and extended capacities improve the energy efficiency of the network. The problem of optimal BS density in the network is investigated, along with the PSR scheme. The proposed PSR scheme can reduce the overall energy consumption of the network by up to 50%, as depicted in the simulation results.

A multi-objective optimization problem is analyzed in [158] for achieving energy efficiency (EE) and spectral efficiency (SE) tradeoff. Transformation of the MOP is done to a single-objective optimization problem (SOP) with the use of weighted sum method. This SOP is complex to solve owing to combinatorial channel allocation indicators, and therefore can be reformulated by introducing the concept of time-sharing. The proposed two layer framework for obtaining an

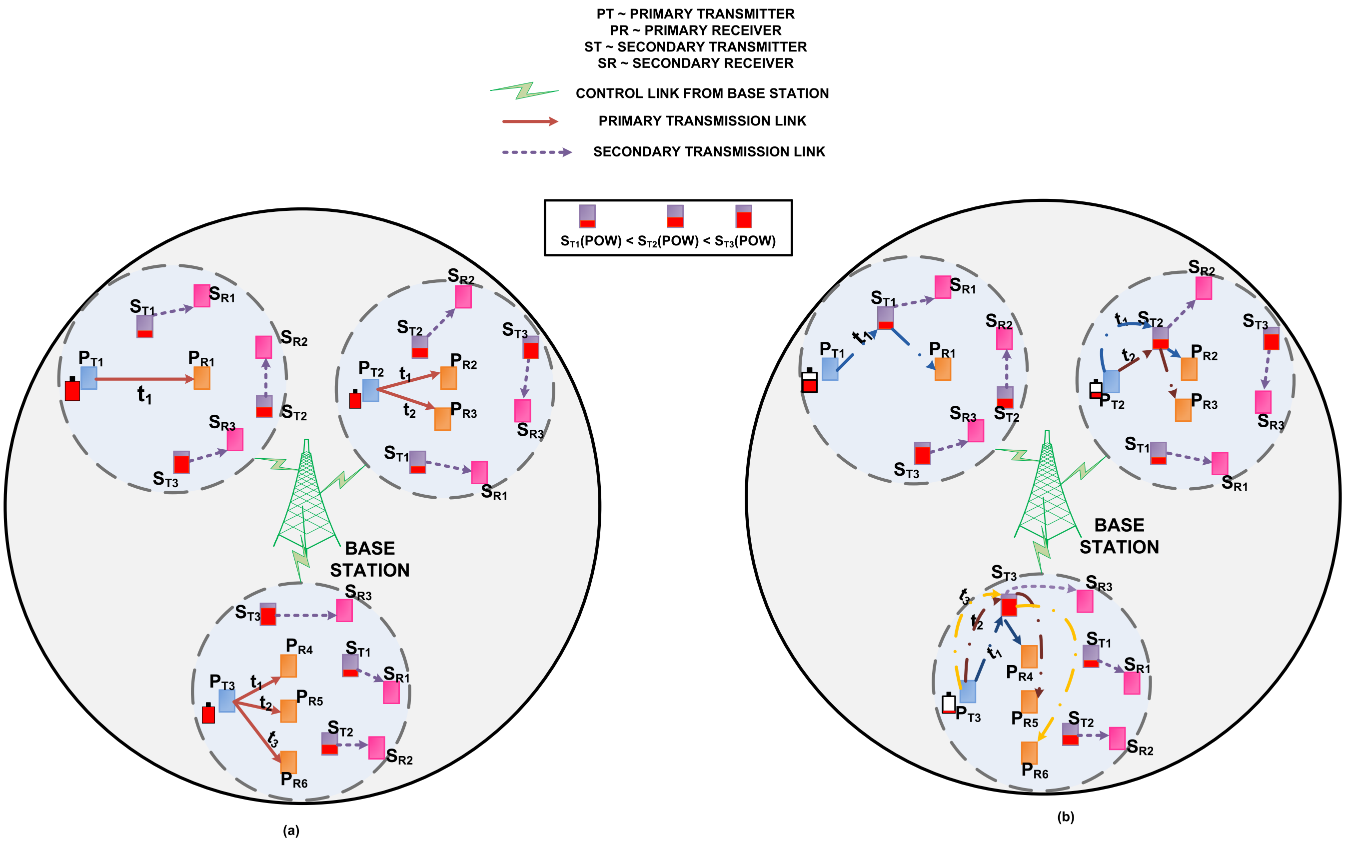

FIGURE 21. Proposed Scenario for Power Optimization of primary user, in spectrum sharing (a) Full batteries of PTs, (b) Batteries of PTs drained (enabling secondary transmission).

optimal solution for the MOP exhibits a low complexity, with fast convergence and is effective in achieving EE-SE tradeoff.

Power allocation problem among the users in spectrum sharing networks has been studied in [159], for proportional, max-min and harmonic fair energy efficiency. These problems are converted to convex forms using interior point method first and then elaborated for achieving fairness among the UEs, with an optimal power allocation strategy involving low complexity. Gong *et al.* [160] investigate a cross interfering spectrum sharing system for optimal power allocation. Double-threshold waterfilling (DT-WF) and double-threshold constant waterfilling (DTCP-WF) have been proposed, with the application of KKT conditions for optimal power control strategies. As is seen, spectrum sharing is expected to bring about a revolution the next generation systems, with a prominent contribution towards energy saving. Of the various listed algorithms, the finest one is [149], as it transmits as well as harvests energy, optimizing the overall network performance. A few open challenges exist, evaluated in the next section.

1) PROPOSED MODEL

Knowing the benefits of D2D communication, UDNs and spectrum sharing in efficient power management, a proposal for power and battery saving is given in this section, as shown in Fig. 21(a) and (b). Here, a single cell scenario is considered, with three cases of spectrum sharing in the cell, each shown in a separate circle within the cell. Three primary transmitters (P_{T1}, P_{T2}, P_{T3}) are considered. Each of the primary transmitters has full battery available initially (Fig. 21 (a)). In that case, they have the ability to provide quality service to the primary receivers, since they have adequate battery to sustain the transmission. The target data rates R_{target} can be effectively met in such a scenario, with appropriate power levels at the receiver, P_r (Fig. 23(a)). P_{T1} is transmitting information directly to P_{R1}, at instant t_1; P_{T2} is transmitting to P_{R2} and P_{R3}, i.e. it is transmitting to two receivers, at instants t_1 and t_2, respectively; P_{T3} is transmitting directly to P_{R4}, P_{R5} and P_{R6}, at instants t_1, t_2 and t_3. In case of low battery level of the primary transmitters, achieving the target data rate R_{target} is not possible through direct transmission between primary transmitter and primary receiver (Fig. 23(b)), due to inadequate receiver power levels, P_r. Transmission will continue, consuming user battery, yet not providing adequate service to the users. In this case, then, the primary transmitters prefer sending the information to the primary receivers via secondary transmitters (Fig. 21 (b)) to optimize its power levels and prolong its battery lifetime. In the considered scenario, for each of the three cases of spectrum sharing considered, three secondary

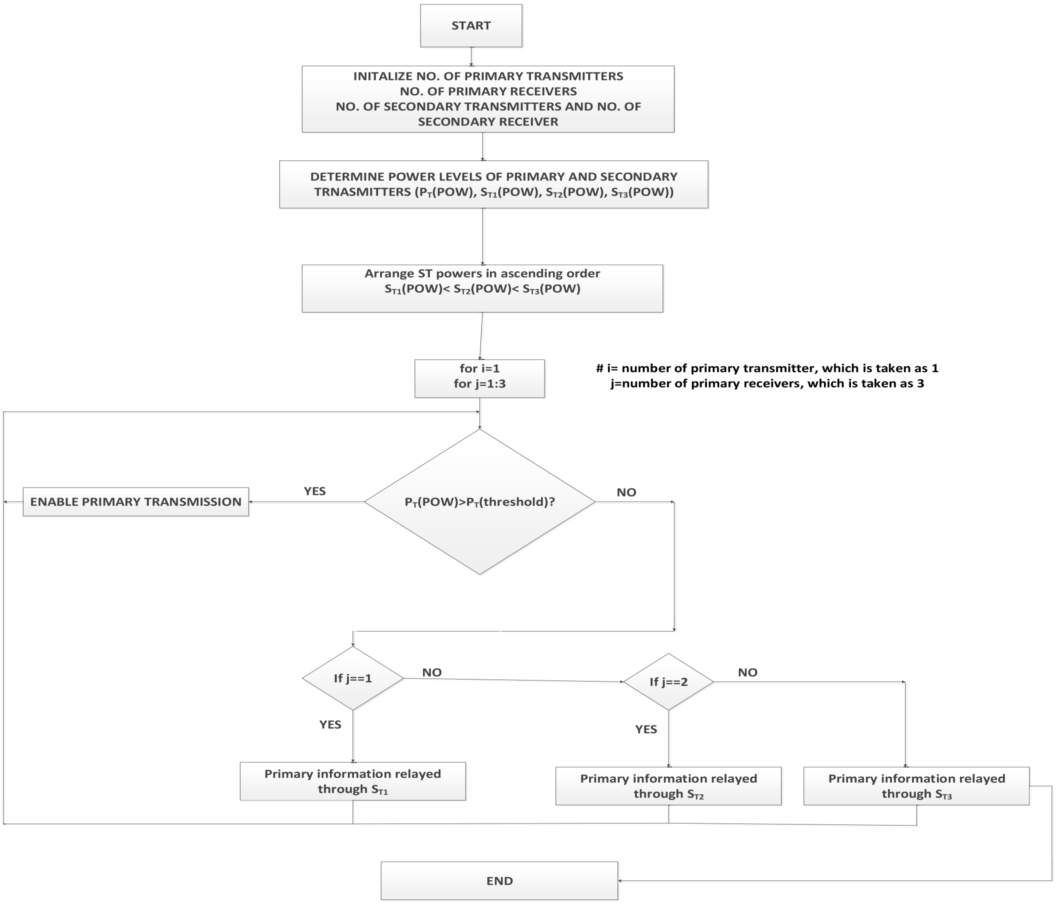

FIGURE 22. Flowchart for proposed scenario.

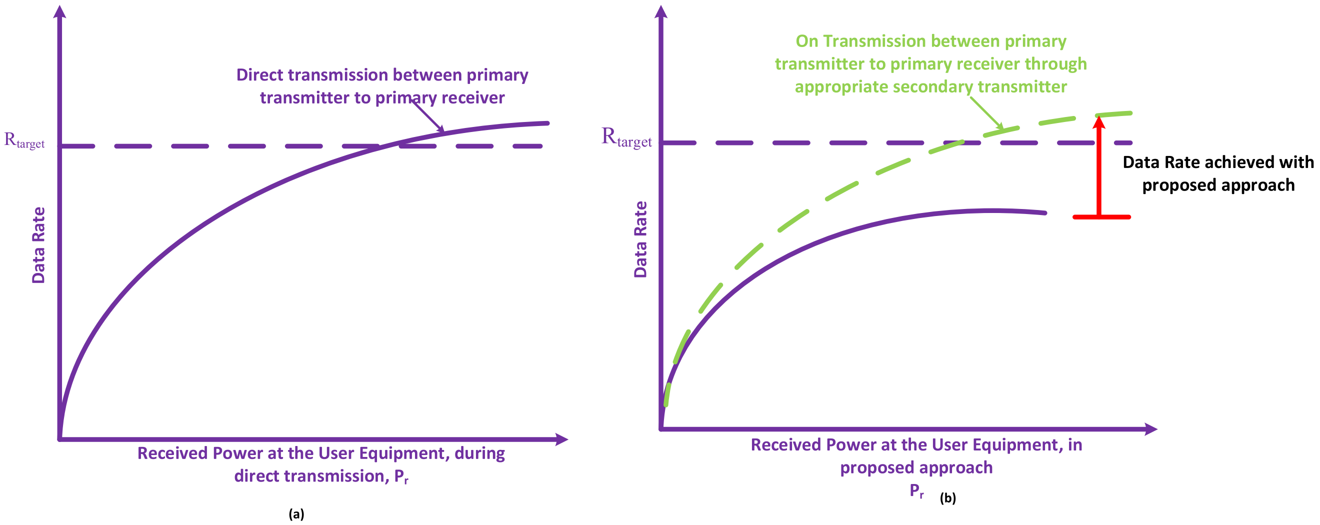

FIGURE 23. (a) Achieved data rate for direct transmission (Full PT battery) (b) Achieved data rate using secondary transmitter, with proposed approach.

transmitters and secondary receiver pairs are taken into consideration: S_{T1}-S_{R1}; S_{T2}-S_{R2} and S_{T3}-S_{R3}. The power levels of these secondary transmitters are such that it is maximum for S_{T3}, lesser for S_{T2} and the least for S_{T1}, denoted as $S_{T1}(POW) < S_{T2}(POW) < S_{T3}(POW)$. S_{T1} (POW) is the power of S_{T1}, and similarly power levels for other two are denoted. The power level of each of the primary transmitter is denoted by $P_T(POW)$.

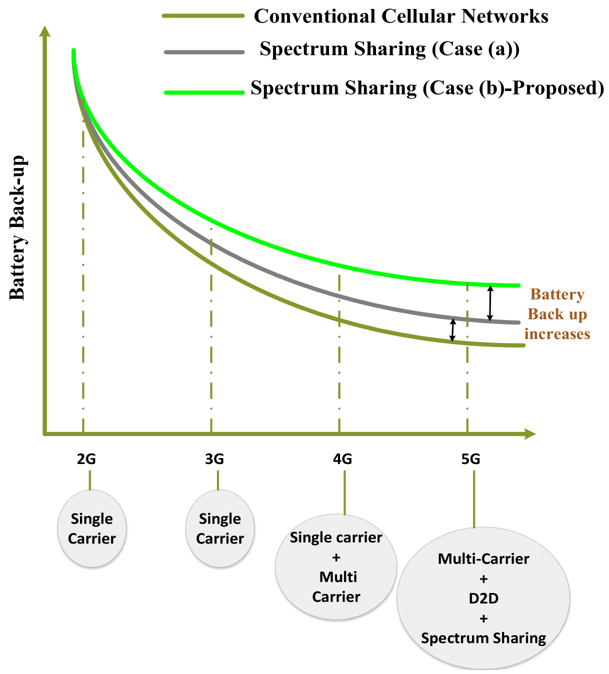

FIGURE 24. Battery Backup Enhancement with proposed approach.

When battery of P_{T1} drains, and it has to choose a secondary transmitter to relay the information to the primary receiver P_{R1}, in order to prolong its battery life, it can choose the least power ST for this task (S_{T1} here). This will help to prolong its battery life, i.e. it will be able to save its draining battery by enabling transmission through the secondary transmitter with the least power. Next, it has been shown that P_{T2} is transmitting to P_{R2} and P_{R3}, at different time instants. This causes more battery drainage. As a result, it chooses S_{T2} to transfer the information to the primary receivers, when short of battery. S_{T1} is not chosen here because of its very less power level. It would not be able to support the information relaying to two primary receivers. Also, S_{T3} has a very high power level, and thus can be used for supporting a larger number of transmissions. S_{T3} is then used when P_{T3} is draining out of battery and has to transfer information to three primary receivers, P_{R4}, P_{R5} and P_{R6}, at different time instants. Each of the secondary transmitters has a secondary receiver, to which it uninterruptedly keeps on transferring the information. With this approach, the target data rates can be met effectively, as is depicted in Fig. 23(b), with rising receiver power levels. Thus, this proposal aims to enhance the battery life of users, with optimized power levels of the involved user equipment, using the technique of spectrum sharing in cellular networks. Energy efficiency of mobile network and mobile terminals is thus not different. These are related to each other.

The entire process flow has been depicted in the flowchart, in Fig. 22. It evaluates the proposal through a step-by-step approach, for a better understanding of the readers. The efficiency of the proposed model is projected graphically, in Fig. 24. If suppose a 3000mAh battery is taken into consideration, powering a 2G, 3G, 4G and a 5G mobile phone, then substantial battery life enhancement is expected with the introduction of spectrum sharing. A further enhancement is possible with the proposed approach, as depicted in the figure. This proposal aims at balancing the trade-off between network energy efficiency and mobile efficiency [190].

E. INTERNET OF THINGS

Billions of users will be connected in a short time period, and this is possible with the influx of the Internet of Things (IoT). The computerized interconnectivity incorporates the use of RFIDs and data communication for connecting each and every object in the world. Wireless sensor networks (WSNs) provide a key platform for IoT, supporting enormous number of applications and meeting the notion of a smart world. To accomplish the objective of a low carbon economy and energy saving, IoT provides a competent solution. . A scenario of IoT and energy in the 5G networks is depicted in Fig. 25. Since infrastructure of IoT largely depends on the wireless sensor networks (WSNs), optimal power control of the nodes is critical. The sensor nodes are resource constrained, causing energy efficiency to be a vital component for their proper functioning. Communication at low power needs energy efficiency solutions.

For data collection, an approach has been introduced in [162], which allows fast collection from farthest nodes and slows from the nearby ones. Enhancement in energy efficiency achieved with this method is up to 18.99%. Energy saving is enabled by the use of sleep modes [163]. Another scheme for enhanced energy efficiency has been exploited in [164] where irrelevant and redundant sensors within the network switch to sleep mode. Further improvement in energy efficiency of 5G IoT networks is achieved with [165], where a combination of pre-caching mechanism and cellular partition zooming (CPZ) are used. It is a versatile approach as it can be used in the wired or the wireless part of the network.

Particle swarm optimization (PSO) algorithm is proposed in [166] to save energy of the sensors networks. Almost 1dBm power saving is possible with the proposed approach. It has been tested for different scenarios but is not convergent for all, thus need further investigation. A power control strategy based on Vague sets is discussed in [167] and allow adaptive power control. Vague sets are used for fuzzy information, and are basically a fuzzy theory. This scheme, based on Vague set theory, can adequately reduce the energy consumption, supporting reliable and efficient communication.

Among the various technologies which are being used in conjunction with IoT, device-to-device (D2D) communication has far-reaching impact [168]. It assures higher QoS and throughput. For D2D communication in C-RAN based networks, a centralized method is for interference avoidance and a distributed scheme for channel selection and power allocation is proposed in [169]. A considerable improvement in energy efficiency is achieved, with the use of game theory in this proposal.

Improvement of energy consumption in industrial Internet of Things (IoT) with cognitive radio (CR) is proposed

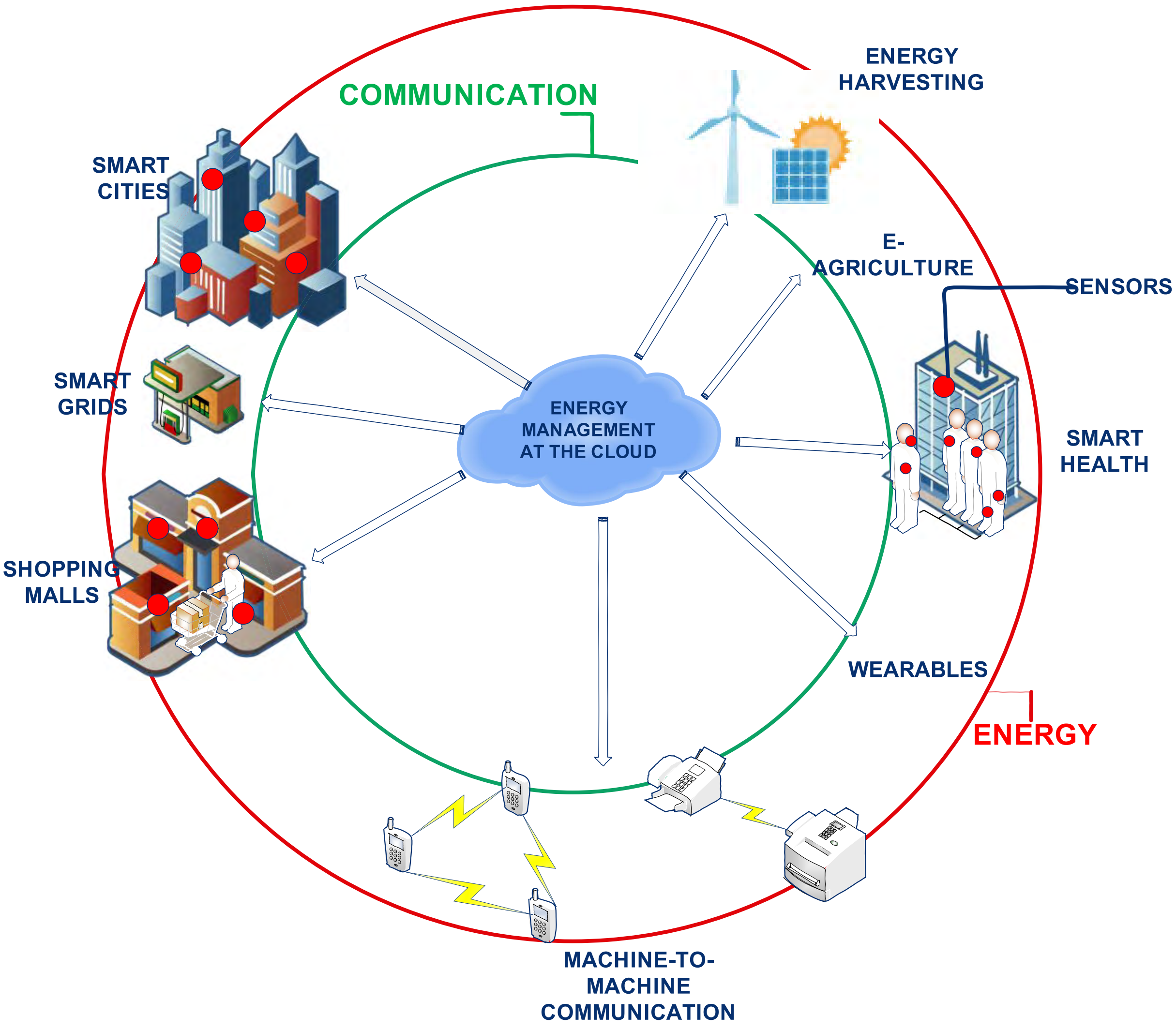

FIGURE 25. IoT and Energy Management.

in [170], where an adaptive power control scheme is initiated, using nonlinear programming. The interference between primary and secondary users is addressed for ensuring quality. The SINR requirements are also taken into consideration for adaptive power control.

The devices forming a part of the IoT environment can be used as a power source and act as harvesting devices. Several techniques for updating the code of such devices have been discussed in [171], which can effectively reduce the resource demand within the system, and improve energy efficiency. Smart energy management is a target of IoT [172]. A device oriented IoT energy management system is introduced in [173]. A number of steps have been taken to enhance the energy efficiency of cellular networks. A distributed topology control algorithm has been proposed in [187] for communication in an environment with limited battery power. However, some studies point out that increased energy efficiency will result in a greater power usage, referred to as rebound effect. This is expected to be very prominent, particularly in the IoT era. Green Cloud RAN assure energy efficiency in UDNs, and help in reducing the operator bills. An implementation perspective in this regard has been discussed in [181]. A green city test bed has been investigated in [183].

On this account, it can be stated that a marked energy saving is possible with the use of IoT in the NGNs. For meeting the objective of a balanced supply and consumption, the concept of Energy Internet (EI) has been introduced. This is advantageous for the next generation networks, however, a number of challenges persist, which need special attention [184]. The various vital technologies of 5G networks have been discussed.

Apart from these technologies, another emerging technology is millimeter wave (mmWave) communication. It can effectively quantify the quality of beamforming and improve the system energy efficiency [174]. Relay systems based

TABLE 6. **5G EE technologies: modelling techniques and perfomance metrics.**

Technology	Reference No.	Algorithm/ Technique	Technique used for modeling	Performance metric
D2D	[84]	Derivative based algorithm	Stochastic Geometry	Energy Efficiency, average sum rate
	[85]	Joint resource allocation and power control	Fractional programming	Energy efficiency
	[86]	Two time-slot physical layer network coding	Taylor series expansion	Energy efficiency, Spectral efficiency
	[83]	Joint power and data rate optimization	Lagragian duality theory and sub gradient method	Energy efficiency, fairness
	[81]	Energy efficient mode switching	Dinkelbach method and concave-convex procedure (CCCP)	Energy efficiency, spectral efficiency
	[91]	Energy efficient power control for D2D	Dinkelbach and branch and bound (BB) methods	Energy efficiency
	[92]	Power optimization with joint resource allocation	Heuristic algorithm	Power consumption at the base station
	[90]	Outer Approximation Algorithm (OOA) for energy efficient resource allocation and cell selection	Charnes cooper transformation	Energy efficiency
	[98]	Joint resource block and power allocation	Lagragian constrained optimization	Sum rate
	[100]	Design and analysis of D2D-Energy harvesting heterogeneous cell networks	Markov Chain	Outage probability
	[87]	Centralized and distributed power control algorithms	Stochastic geometry	Coverage probability
	[89]	Power Allocation and Network mode selection	Simulation Based	Energy Efficiency, Data Rate
UDN	[106]	EE maximization with massive MIMO	Stochastic Geometry	Energy Efficiency
	[107]	EE and AEE of macro-picocell heterogeneous networks	Simulation Bases, along with branch and bound (B&B) algorithm	Energy efficiency, area energy efficiency
	[109]	Unified mathematical model for cost, energy and spectrum efficient UDNs	Linear weighted scheme and Nash-product	Energy efficiency, Spectral Efficiency, Cost efficiency
	[110]	Frequency reuse strategies for maximizing EE and SE	Lagrange Interpolation	Energy efficiency, spectral efficiency
	[112]	Joint power control and user scheduling in UDNs	Game theory	Energy efficiency, outage probability
	[113]	Determination of frequency reuse factor in randomly deployed dense networks	Karush-Kuhn-Tucker (KKT) conditions	Energy efficiency, Spectral Efficiency
	[114]	High resolution Cell breathing strategy for UD-Hetnets	Lagrangian Theory	Energy efficiency
Massive MIMO	[125]	Max-min Algorithm	Linear Programming	Total transmission power
	[126]	Energy efficiency scaling Laws	Random Matrix theory [177]	Energy Efficiency
	[128]	AO-BS Algorithm	Bisection Method	Energy Efficiency
	[130]	EE D2D with massive MIMO	Stochastic geometry	Energy Efficiency and Average Sum Rate
	[116]	Self backhaul small cells and massive MIMO	Concave Convex procedure iterative method [162]	Energy efficiency, spectral efficiency, cost, energy consumption
	[131]	Distributed energy efficiency power control algorithm	Evolutionary game theory (EGT)	Energy efficiency, fairness
	[134]	Antenna grouping and selection	Binary search algorithm	Energy efficiency
Spectrum Sharing	[151]	BCM Mechanism	Cat Swarm optimization	Throughput
	[153]	Spectral efficiency and energy efficiency analysis of a two-tier HetNet	KKT conditions	Spectral efficiency, energy efficiency
	[156]	Time averaging radio resource allocation	Lagragian method	Throughput
	[158]	Partial spectrum reuse for energy cost saving	Exhaustive search algorithm	Energy cost of network
	[159]	Analysis of multi-objective optimization problem	Weighted sum method	Energy efficiency, Spectrum Efficiency
IoT	[163]	Fast for far and slow for close	Simulation based	Energy efficiency, end to end delay
	[166]	Cellular partition zooming and pre caching	Simulation based	Energy Efficiency
	[167]	Particle Swarm Optimization Algorithm	Particle Swarm Optimization (PSO) Theory	Energy Efficiency
	[168]	Vague Theory based Power Control	Vague Theory	Transmission power
	[171]	Adaptive Power Control Algorithm	Lagragian Theory	Transmission power, weighted throughput

on mmWave communication features are capable of providing energy-efficient solutions [175]. mmWave communication, along with massive MIMO can greatly improve the coverage area of the base station, enhancing the network QoS. In a mmWave network with several cellular operators, spectrum sharing can act as a sustainable alternative to

TABLE 7. Standarization agencies.

S. No.	Agency	Objective
1.	3GPP	Provide Technical Solutions for energy efficiency (Rel 14 and 15)
2.	ITU	Reducing Carbon footprint(ITU-T Study Group 5)
3.	ETSI	Low energy devices in IoT [178]
4.	ATIS	Enhance equipment's energy efficiency [179]
5.	5GPP	Up to 90% energy saving in wireless networks
6.	IEEE	Energy efficient distribution of content (IEEE Power and Energy Society) [180]

traditional spectrum allocation technique. With large number of antennas, the spectrum sharing implementation can be significantly enhanced [185]. The various discussed techniques have achieved significant savings in the MNO costs, and in the CO_2 emissions [186]. Clearly, all the evolving technologies are related to each other, and are supportive in terms of green networking. When used in conjunction, a single holistic approach can be intensely revolutionary for green communication in the NGNs. Yet, some open challenges need to be critically addressed, before their implementation. Thus, various 5G technologies, which are capable of improving the network energy efficiency have been reviewed. These techniques are the key enablers of green communication in the next generation networks. A summary of the various discussed algorithms discussed has been given in Table 6. The algorithms and techniques used by the researchers have been given in the table, along with the metric optimized, in the table. These techniques, when used in conjunction, can be fruitful for achieving the spur of green communication in the next generation networks. The effect of these technologies on the network performance as a combination of two or more technologies has also been reviewed, like UDN and massive MIMO [115], D2D and massive MIMO [129], and the like. Intelligent and efficient techniques towards green communication include caching and mobile computing. The various algorithms have been tested in theoretical simulations. But these must be tested in test beds, where they are subject to the constraints of the real world environment. This provides a great platform for hand on experiences of the techniques. A green collaboration among the network operators is essential for green communication. It includes virtualization implementation, consolidation of devices and data centers and an efficient use of servers.

VI. RESEARCH CHALLENGES

The various energy efficient techniques discussed in the preceding sections are beneficial for the 5G scenario. Yet, a number of research challenges be existent, which need to be disparagingly redressed by the research community, for the feasibility of these technologies for green communication in NGNs. The various techniques studied in the paper are extensively being studied separately also. Combining together all these into an all-inclusive approach can bring about a upheaval in green communication.

When using BS sleep modes, it is necessary to specify its waking time as well. It is because the BS needs to turn on when the load increases at another instance of time. The unnecessary wastage of energy during turn on/off of the base station must be paid attention to. With the proliferation of the IoT, a tremendous rise in the Machine-type Communication (MTC) will occur. Implementing BS on/off strategies in such networks are challenging. Also during the sleep intervals, the users of the switched off cell are served by the neighboring cell's BS. The operator whose BSs are switched off have to pay to the neighboring operator, servicing its users. This price should be profitable for the operators, otherwise there is no advantage of saving energy by the sleep modes.

Additionally, the evolving networks are random in nature. Such a random behavior can be effectively studied by the tools of stochastic geometry and random matrix theory [176]. The devices can be allowed to learn from their past experience and suitably respond, in a self-organizing manner, providing an open field to the researchers in this field, towards green networks. Also, the rising count of devices results in risen radiation levels and the carbon footprint. New and different antenna configurations, along with less radiating surface materials can be suitable for reducing the amount of radiations from user equipment. Recyclable materials can be helpful in carbon footprint reduction, since a large amount of CO_2 is emitted during the manufacturing process itself.

Powering and backhauling in ultra-dense networks (UDNs) is a prime deployment concern. In the ultra dense deployments, the power requirements of each and every small cell base station are required to be taken care of. Looking into this issue, the concept of self-backhauling has come into picture. This is still an open research field. Small cells powered by renewable sources of energy, like solar energy, wind energy, are being widely deployed. But such deployments have not been able to support base station sleep modes yet. An important metric to be addressed is end-to-end latency (delay). This is related to energy efficiency (EE), but trade-off between the two parameters has not gained much attention of the research community. In the world of billion connected devices at one instant, the target of less than 1 millisecond latency has to be achieved. This aspect needs a paramount attention.

Massive MIMO is an enormously energy efficient technique. However, the large number of antennas involve enormous amount of overhead, causing unnecessary power consumption. Also, additional cost is a major drawback. Massive MIMO involves large scale processing, which needs further attention. An energy efficient power allocation problem for spectrum sharing has been investigated in [182], for a cost-efficient network, capable of simple implementation. Spectrum sharing can efficiently enhance energy efficiency, as discussed, however, regulatory issues for spectrum access need to be addressed, looking into the aspects of security. Economic concerns regarding spectrum sharing are also critical.

TABLE 8. Ongoing projects.

S. No.	RESEARCH PROJECT	RESEARCH AREA	HTTP Location
1.	TRIBE	To enhance social behavior of subscribers towards energy efficiency	http://tribe-h2020.eu
2.	EUFORIE (European Futures for Energy Efficiency)	To meet the target of secure, clean and energy efficient environment	http://euforie-h2020.eu
3.	Zero Emission Cities	To reduce demand for fossil fuels and green house gas emissions	http://www.wbcsd.org/Projects/Zero-Emissions-Cities
4.	GREENNETS	To reduce power consumption and CO2 footprint	http:// www.greennets.eu/
5.	GreenTouch	To achieve up to 98% energy reduction till 2020	http://www.greentouch.org
6.	mmMAGIC	To enable cost and energy-efficient solutions for 5G millimeter wave deployments	https://5g-mmmagic.eu/project/
7.	NetCodMod5G (Network Coded Modulation for next generation wireless access network)	To support base station cooperation, to enable energy efficiency and bandwidth efficiency	https://www.york.ac.uk/electronics/research/communication-technologies/projects/turbo-codes/#netcod
8.	Resource and Topology management for 5G systems	Adaptive, energy efficient management of network topology with optimal resource allocation schemes	https://www.york.ac.uk/electronics/research/communication-technologies/projects/turbo-codes/#netcod
9.	5G NORMA (Novel Radio Multi-service adaptive network architecture)	To develop a novel architecture for 5G, ensuring security, cost efficiency and energy efficiency	https://5g-ppp.eu/5g-norma/
10.	Flex5GWare (Flexible and efficient hardware/software platforms for 5G network elements and devices)	To deliver hardware and software platforms which reduce the energy consumption of the networks	https://5g-ppp.eu/flex5gware/
11.	METIS-II	To develop an energy-efficient network design	https://metis-ii.5g-ppp.eu/
12.	5G-ENSURE	To formulate a security architecture for 5G	http://www.5gensure.eu/
13.	CHARISMA (Converged Heterogeneous Advanced 5G Cloud-RAN Architecture for Intelligent and Secure Media Access)	To enhance spectral efficiency and energy efficiency of 5G networks, with security guarantee	https://5g-ppp.eu/charisma/
14.	CogNet	To build an intelligent system of insights and action, supporting green communication, when it is available in the network	https://5g-ppp.eu/cognet/
15.	VirtuWind	To use wind energy as the prime source of energy generation	https://5g-ppp.eu/virtuwind/
16.	5G-Crosshaul	To provide fronthaul and backhaul solutions to 5G networks, for reducing CO2 emissions	https://5g-ppp.eu/xhaul/
17.	FANTASTIC	To develop a multi-service air interface for improving energy efficiency	http://fantastic5g.eu/
18.	5Green	To design eco-friendly 5G networks, for energy efficient mobile networks	https://wireless.kth.se/5green/

Since energy is not capable of encryption, therefore it is highly susceptible to security attacks. Energy state of devices within a network can be forged, resulting in energy forgery attack. Energy state privacy preservation issues require attention. Also, information can have a backup, but no backup is available for energy. This is an area of apprehension for the researchers. Energy harvesting is being extensively worked upon, by harnessing energy from RF signals and ambient sources. Yet, use of renewable resources is dynamic and naturally sustainable. For example, harvesting energy from the sun (solar energy) is variable during day and night hours. Also, sufficient amount is not available during cloudy/rainy days. Apart from this, the harvested energy must also be efficiently allocated to the users. Consequently, a number of research challenges persist, still, hindering the path of a perfectly green cellular network.

VII. CONCLUSION

Energy efficiency in cellular networks is a rising concern for the mobile network operators (MNOs). The issues not only involve the cost, but also the escalating CO_2 levels in the atmosphere and health concerns, which are dreading along with the growing technology and a corresponding subscriber and device count. These aspects have been briefly overviewed initially, in the paper. Since maximum portion of the energy is consumed by the base station, different techniques for controlling its power at the base station itself have been evaluated.

The evolving 5G networks support a number of technologies, like massive MIMO, device-to-device (D2D) communication, spectrum sharing, IoT. All these are capable of supporting green communication in the future cellular networks, and have been extensively surveyed from this perspective. Though these are in favor of green networking, yet, many challenges exist and have been discussed. This paves way for the new research in this field. For prolonged battery life, proposal has been made in this paper, using spectrum sharing. The proposal aims for a longer battery life of the primary users in a spectrum sharing scenario of 5G networks. It is an effective technique of saving user battery, without compromising the Quality of Service (QoS) in the cellular networks.

As already stated, among all the evolving technologies, one aspect which cannot be compromised is the network security. For green cellular communication, secure power optimization is essential. This area remains an open research field for the next generation networks. This and other research issues have been evaluated n the paper. A list of abbreviations used in the paper is given in Appendix B. The organizations involved in standardization activities and the ongoing projects for enhanced energy efficiency are given in Appendix A and C.

TABLE 9. List of abbreviations.

Abbreviation	Explaination
3GPP	Third Generation Partnership Project
4G	Fourth generation
5G	Fifth generation
5GPP	5G Infrastructure Public Private Partnership
AEE	Area Energy Efficiency
AN	Artificial Noise
AO-BS	alternative optimization plus bisection searching
ASR	Average Sum Rate
ATIS	Alliance for Telecommunication Industry Solutions
AWGN	Additive White Gaussian Noise
B&B	Branch and Bound
BCM	Best Cooperation Mechanism
BDMA	Beam Division Multiple Access
BS	Base Station
CAPEX	Capital Expenditure
CDMA	Code Division multiple access
CSI	Channel State Information
CSO	Cat Swarm Optimization
D2D	Device-to-device
DF	Decode and forward
DoF	Degree of Freedom
DRX	Discontinuous reception
DTCP-WF	double-threshold constant waterfilling
DT-WF	Double-threshold waterfilling
DTX	Discontinuous transmission
EE	Energy efficiency
EGT	Evolutionary Game Theory
EH	Energy Harvesting
ETSI	European telecommunication Standards Institute
FBMC	Filter Bank multi carrier
FD	Full duplex
Gbps	Gigabits per second
GREEN	Globally Resource Optimized and Energy Efficient
Gt	Giga Tones
HD	Half Duplex
HetNet	Heterogeneous Network
ICT	Information and Communication Technology
IoT	Internet of Things
ISI	Inter-symbol Interference
KKT	Karush-Kuhn-Tucker
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MOP	Multi-objective Optimization
MRT	maximum ratio transmission
Mt	Million Tones
OAA	Outer Approximation Algorithm
OPEX	Operating Expenditure
PC	Pilot Contamination
PSR	Partial Spectrum Reuse
RAN	Radio Access Network
RAPS	Resource allocation using Antenna Adaptation, Power Control and Sleep Modes
RB	Resource Block
SCA	Small Cell Access Point
SC-FDMA	Single carrier frequency division multiple access
SINR	Signal-to-interference-plus-noise ratio
WF	Water Filling
ZFBF	Zero forcing Beamforming

APPENDIX

A. STANDARDIZATION AGENCIES

The various standardization agencies have been given in Table 7.

B. TABLE OF ABBREVIATIONS

C. LIST OF ONGOING PROJECTS

The various ongoing projects are listed in Table 8.

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