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An Overview of Recent Developments in Energy Efficiency of Wireless Networks and Emerging Technologies in 5G Networks

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Abstract: *During the last two decades, there has beena tremendous growth in wireless communication services, whichhas dramatically increased the number of necessary radioaccess components to provide the adequate capacity andacceptable quality of service (QoS). The power cost for operatingthis huge number of radio Base Stations (BSs) is underserious consideration by the mobile communicationindustry and recent research efforts have focused on energyefficient design and optimization of the radio access of the next-generation networks in order to reduce the energy consumption andmobile network operator'soperational expenditure (OPEX).In this paper, we have surveyed various techniques for the energy efficiency of the upcoming 5G networks.The primary focus is on the use of advanced physical layer techniques such as multiple-input multiple-output (MIMO) antenna, small cells, Mm-Waves and cooperative communication, etc.; new network architectures such as heterogeneous networks, distributed antennas, D2D communication, Relay and multi-hop cellular,etc.; as well as radio and network resource management schemes such as dynamic power saving, traffic balancing among multiple RATs coordination, discontinuous transmission (DTX), etc. have been proposed to address this issue. Along with this, the importance of green communication including simultaneous wireless power and information transfer (SWIPT) andgreen antenna has been analyzed for 5G networks. In this paper, we overview these technologies and present the state-of-the-art on each aspect. Some challenges that need to be solved in the area are also described.*

Key Words:*5G;Energy Efficiency;Green Communication;Small Cells; MIMO;D2D;SWIPT.*

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I. INTRODUCTION

By 2025, it is expected 5G to have 2.6 billion subscriptions accounting for 29% of all mobile subscriptions at that time and generating 45% of the world's total mobile data traffic [1].

Modernizing existing networks, improving network performance and increasing user experience continue to be at the core of every service provider's. In 2025, it is estimated that there will be 8.9 billion mobile subscriptions, out of which around 90% will be for mobile broadband.The number of smartphone subscriptions is forecasted to reach 7.4 billion in 2025, or 83% of all mobile subscriptions.Mobile subscriptions per technology are shown in figure1[1].

In general, both the rising number of smartphone subscriptions and an increasing average data volume per subscription, fueled primarily by more viewing of video content, are driving traffic growth.Globally, the increase in mobile data traffic per smartphone can be attributed to three main drivers: improved device capabilities, an increase in data-intensive content and more affordable data plans.

Three generally accepted paths to increase the system capacity are allocating additional spectrum through re-farming or introducing new bands, improving the spectral efficiency of the technologies, and cell densification. These paths are not completely independent from each other and improving one path may effect on the others. For example, network capacity does not improve proportionally with decreasing cell size, as smaller cells may interfere more with each other and negatively affect the spectrum efficiency.

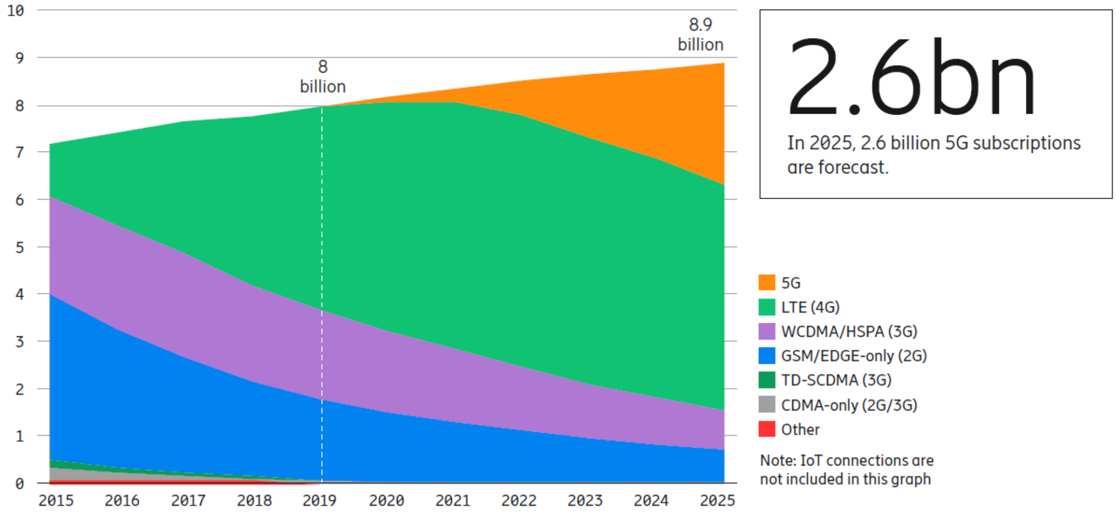

Fig.1: Mobile subscriptions by technology (billion) [1].

With the rapid growth and evolution of information and communication technology (ICT), energy consumption is also growing at a very fast rate. It has also been reported mobile operatorsare among the top energy consumers. Thus, there is an urgent need to shift from pursuing high capacity and spectral efficiency to energy efficient design. By reducing power consumption of mobilenetworks,it can improve their energy efficiency.

The energy efficiency of 5G networks is expected to be increased 100+ times compared to IMT-2000[2, 49].Many in the industry think 5G will achieve more ambitious values for energy efficiency and it is expected to reach an improvement greater than 90% over LTE [48]. Network energy efficiency is one of the main key capability of IMT-2020 is shown in figure2 [2].

The ICT sector is responsible for approximately 3% of the world energy consumption and 2 % of the equivalent CO2 emissions, while almost 60% of the cellular networks energy is spent at the operation of Base Station (BSs) with overall energy efficiency of 3.1% [3]. In addition to that, the exponential growth of wireless data traffic calls for an ultra-dense deployment of the wireless access components of next generation mobile networks, which in turn will yield a huge power consumption increase. Consequently, both mobile telecommunications industry and research community are already considering ways to decrease the costs of operating such a huge number of BSs.

However, although technical issues such as spectral efficiency and QoS provisioning have been extensively studied, little has been achieved in terms of energy consumption in mobile networks.

Actually, mobile networks are major candidates forenergy savings. Traditional cellular network planning andoperation are driven by the requirement that user requestsshould be served with acceptable quality at any time andany place. Mobile networks are mainly designed for hightraffic load operating scenarios of the network with continuouslyactive BSs, in order to guarantee area coverageand QoS to the mobile customer. In practice, networks areover-provisioned with excess capacity most of the time asthe actual telecommunication traffic load during regular daily network operation cycle, experiences high trafficload variations. Therefore, many BSs are beingunderutilized for more than half of the year, and as a result,large portions of energy are wasted without carrying significant traffic load [3].

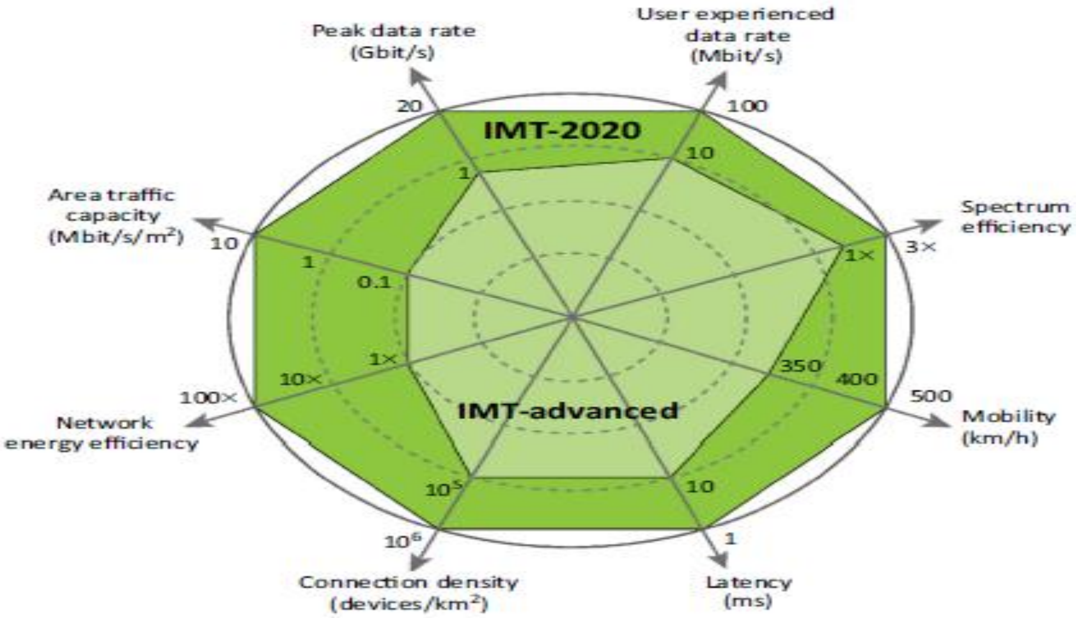

Fig.2: Key capabilities of IMT-2020[2].

This has led to joint academic and industrial research for developing energy saving techniques like the EARTH project [4],`green radio' project [5], OPERANet[6], and eWIN [7]to reduce the power consumption as well as to save the operator from incurring the huge cost of deployment of a new BS.

It is clear from the previous projects that low-power circuit design, high-efficiency PA and digital signal processing (DSP) technologies, advanced cooling systems, adequate EE metric and energy consumption models, cell-size deployment, various relay and cooperative communications, adaptive traffic pattern and load variation algorithms, green cellular and energy-efficient network resource management techniques, are the highlights of energy-efficient wireless communications.

In this paper, the state of the art in models and schemesfor energy-efficient wireless networks are introduced. Somechallenging issues in these areas are also discussed. In particular,Section 2 analyzesenergy consumption in cellular networks.Section 3 analyzes the influence of the EE metricand energy consumption models on energy-efficient wirelessnetworks. Section4 describesradio resource management andhow to make use of dailynetwork traffic variations and various QoS requirements to save energy. Section 5 discusses various network deployment strategies including heterogeneousnetworks,relay andcooperative communications and D2D communications to save energy. Section 6 discussesenergy efficient techniques. Section 7introduces proposed energy efficient architecture.Future research challenges are definedin Section 8. Finally, we conclude the paper in Section 9.

II. ENERGY CONSUMPTIONIN CELLULAR NETWORKS

This section gives an overview on energy consumption in cellular networks. Energy consumption of cellular networks can be viewed from twodifferent but related perspectives, i.e., the operator’s (or system-level) perspectiveand the Mobile Station’s (MS’s) perspective.

D. Lister et al. [8] is pointed out that the energy bill accounts for at least 32% of the Operation Expenditure (OpEx) in India and approximately 18% in the mature European market, operators foresee energy efficiency of their networks as animportant component to reinforce their business competitiveness.

In a cellular network, BSs are the most energy demanding component, responsiblefor the consumption of the most energy in the network.Therefore, there is a great potential to save a reasonable amount of network powerif the energy consumption of BSs could be reduced.

In order to achieve energy efficient in mobile networks, energy conservationfor MSs also needs to be considered. While mobile devices in cellular networksalways need to be associated with their BSs, Wi-Fi affords a high initial costof associating with an Access Point(AP). However, as Wi-Fi, e.g., as a MS interface, typicallyuses the power-save mode, the cost of maintaining this association is low. When linked, the energy consumed by a data transfer is proportional to the volume of thedata transferred and the level of transmission power. Moreover, there are further energy consumption components in a mobile devicewhich are dependent on the type of the platform used. These components includethe CPU, memory, screen size, chipset, etc. However, their energy consumption canbe taken collectively as the energy consumed for electronic processing. In addition,other factors also indirectly affect the battery energy of an MS, including the type ofapplication running, the ratio between the amount of downloaded and uploaded data, etc.

The network's power consumption had broken down and showed that BSs alone represented around 57% of the entire network consumption and showed that between 50% and 80% of the BSs' consumption is caused by the power amplifier, as shown in figure 3 [9].

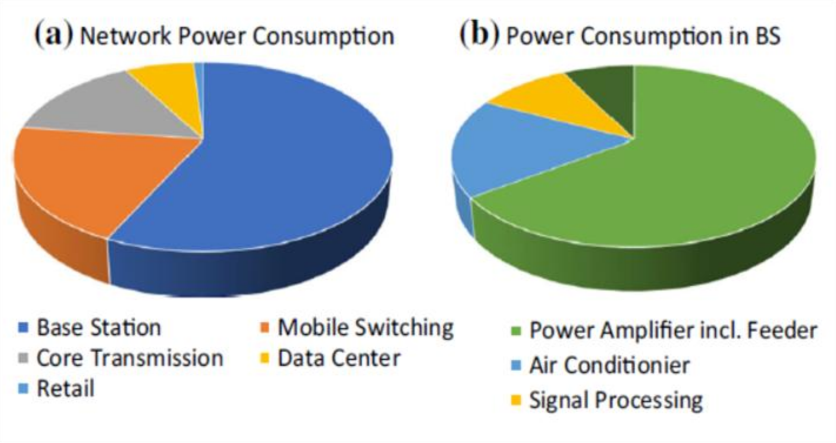

Fig. 3: Power consumption in cellular networks Adapted from [9]

This led the International Telecommunications Union (ITU) to consider energy efficiency as one of the key capabilities of 5G.In addition, there is a 15-20% rise of energy consumption for IT sectors and is expected to double every 5 years. These results have forced major operators to begin finding ways to improve energy efficiency in their operation.

Therefore, from the operators' perspective, energy efficiency (EE) not only has great environmental benefits and represents social responsibility in fighting climate change, but also has important economic benefits. Thus, it is serious when designing mobile networks to shift from pursuing optimal capacity and spectral efficiency to efficient energy usage.

From the users' perspective, energy-efficient wireless communication is also imperative.According to the 2010 wireless smartphone customer satisfaction study from J. D. Power and Associates [10]and based on the data in [11], which reflects the same problem of battery life of the smart phone, up to 60% of the users complained that battery endurance was the greatest barrier when using 3G services. Without a breakthrough in battery technology, the battery life of the terminal sets will be the biggest limitation for energy-hungry applications (e.g., video games, interactive video, video sharing, streaming multimedia, and mobile TV and 3D services).

The battery capacity is increasing only 1.5x per decade and has always been a concern for the user.So, to satisfy users' demand of battery life, energy efficiency in mobile networks is imperative. Furthermore, High power radiated by handsets while in use for a long time tend to harm the user in close proximityand this represents another factor under consideration for the health of the user.

III. ENERGYEFFICIENT METRIC ENERGY CONSUMPTIONMODELS

A suitable EE metric is of primary importance in overallenergy-efficient network design since it is directly related tothe optimized decisions across all the protocol layers.

In literature, several different EE metrics have been usedand the most popular is 'bits-per-Joule', which is defined as the systemthroughput for unit-energy consumption. F. Meshkati et al. [12], the energy consumption models only considerthe transmit power associated with data transmission rate;however, transmit power is only a part of the overall energybudget. When the energy consumption of other parts (e.g.circuit power consumption of the transceiver) is taken intoaccount, the energy-efficient schemes might not be suitable.

O. Arnold etal. [13] investigate energy consumption models of macro cellular andmicrocellular BSs. In thesemodels, the energy consumed at the BS with no trafficload, nominated the 'static energy part', and the 'dynamic energy part', which depends on the traffic load, are added togetherto give the total energy consumption of the BS. Itis found that the power consumption depends largely on thetype of BS. In particular, the energy consumption ofa macrocell BS is dominated by the static part and does notsignificantly depend on the transmission parameters of eachuser.However, for a microcell BS, the energyconsumption is mainly depending on the dynamic part(e.g., allocated transmit power and the number of allocatedsubcarriers).

The EE metric should include all the energy consumption such as transmission power, circuit power (computation in algorithms and protocols) and signalingoverhead in the entire network; and, tradeoffs must bemade between them such that the energy savings in onepart would not be opposed by increased energy consumptionin another part.However, EE is not the only figure of merit for designingmobile networks. Spectral efficiency, deployment cost, networkcoverage and QoS requirements (such as transmissionrate and delay) are also important ’metrics’ that should beseriously considered.

The next generation architectures focus on developing new technology, cell deployment strategies and resource allocation policies to improve the energy efficiency of a mobile network.

IV. ENERGY-EFFICIENT RADIO RESOURCE MANAGEMENT

To well enhance energy efficiency, the traffic variation characteristic of different users should be well exploited for adaptive resource management. Various resources, such as transmit power, BSs, antennas, and frequency bandwidth, are expected to be jointly optimized. Based on different realistic power models, different resources may be used with high priority.

Resource allocation techniques that make the most efficient use of the RF amplifier have the potential to improve energy efficiency significantly. Such energy reductions could lead to further energy savings through switching off transceiver equipment and BS cooling.

By exploiting different service quality requirements from multiple users, new scheduling and resource allocation schemes can be re-designed from the perspective of energy efficiency. The resource allocation among multiple RATs is also a possible way to further save energy.

Energy-efficient radio resource management is one of the powerful ways to reduce energy consumption of wireless network systems. In this section, we mainly focus on energy saving under low-traffic loads and exploiting QoS requirementsfor a variety of applications.

4.1.Energy Saving Based on Traffic LoadVariations

Most current network dimensioning is peak-load orientedto satisfy the users’ QoS requirements. In fact, much previouswork [14] shows that daily traffic loads at BSsvary widely over time and coverage area. Thus, a lot of energy iswasted when the traffic load is low. Vendors and Operatorshave already realized this problem and taken action. Forinstance, Alcatel-Lucent announced that a new feature oftheir software upgrades, called dynamic power saving (DPS), could bring up to 27% power consumption reductions forBSs deployed by China Mobile [15]. M. Marsan et al. [16], optimal power-saving schemes using cell switch-off areanalyzed and it is proved that a 25-30% energysaving is possible by simply switching off the active cellsduring the periods when their traffic is low. T. Chen et al. [17], some potentialapproaches to make energy consumption of BSs scale withthe traffic load across time, frequency, and spatial domains arepresented. It is also shown that the maximum energy-savinggain can be achieved by jointly reconfiguring the bandwidthand the number of antennas and carriers according to the trafficload. G. Auer et al. [18], multi-RAT (multiple radio access technologies) is proposed bythe EARTH project to take the advantage of the dynamicdistribution of the traffic load among different radio accessinterfaces.

The energy efficiency of a network can be improved by both reducing RF transmit power and saving circuit power. To enhance energy efficiency, the traffic variation characteristic of different users should be well exploited for adaptive resource management. Examples include discontinuous transmission (DTX), BS and antenna muting, and traffic balancing among multiple RATs.

DTXis an intuitive way to save BS energy by switchingoff the transceivers when there is no need to transmit or receive. As continuous transmission and reception consume asignificant amount of power, DRX and DTX are an attractive way for BS powerconsumption reduction.

Under low traffic load conditions, the BS is likely to have more bandwidth available to transmit data to users than is actually required at that time. One frequency domain approach is exploiting spare bandwidth resources to reduce energy consumption.

Due to the fact that channel capacity scales linearly with the available bandwidth but logarithmically with the radio transmission power, it is possible to trade spectral for energy efficiency, and achieve energy savings while retaining QoS. Rather than use a complex but spectrally efficient modulation scheme (e.g., 16QAM) with a narrow bandwidth, it is possible to use a simpler modulation scheme (e.g., QPSK) with a wider bandwidth.

In addition, analysis of data traffic in wireless networks show that the traffic load is typically very uneven across the cells (i.e.; in peak hours, most of the data traffic is carried by only small number of the cells in the network). Therefore, techniques that minimize energy consumption across varying traffic load conditions are an important issue.

4.2. Service Differentiation

Energy saving should not only exploit the traffic load variations,but also the diversity of the QoS requirements. With the evolution of cellular systems and the popularity ofsmart phones, such as the iPhone, more and more massiveapplications will appear in cellular networks. In particular,some applications, such as video conferencing, web-basedseminars, and video games, require real-time service; andother applications, such as email, and downloading files foroffline processing, are delay tolerant. Hence, it is beneficialto differentiate the types of traffic and make the energyconsumption scale with the traffic type.

In a store-carry-and-forward (SCF) scheme [19], whenthe application data is not delay sensitive, a user can firsttransmit the data to a mobile relay (for example, a vehicle)which carries the message close to the BS, and then the mobilerelay retransmits the data to the BS. Numerical results show that, for delay insensitive services, a factor of more than30 in energy savings can be obtained by SCF compared withdirect transmission.This is perfect for an elastic service.

V. STRATIGIES FOR ENERGY-EFFICIENT NETWORK DEPLOYMENT

Network deployment strategies are always among the hottopics in cellular communications. However, early work inthis area is mainly focused on network performance, suchas coverage, spectral efficiency, and capacity [20]. Recently,as energy consumption has become a primary concern,energy-efficient network deployment strategies have attractedincreasing interest.

B. Badic et al. [21] investigate the optimal cell size in terms of energyconsumption, where thetradeoff between EE and deployment cost is also discussed.In the following, energy-efficient deployment strategies for emerging heterogeneous networks (mix of macro-cells, micro-cells, pico-cells, and femto-cells), various relay and cooperative communications and D2D communications are also worth considering.

5.1. Heterogeneous Networks

For energy efficiency, the optimal layout of microcellsoverlaying conventional macro-cells is investigated by F. Richteret al. [22]. In particular, simple energy consumption models ofdifferent base-station types areprovided, where the energy consumption at the BSis modeled as the sum of the transmit-power dependentand independent parts, respectively.Specifically, the energyconsumption of the power amplifier(PA), the feeder loss, and the extra lossin transmission-related cooling, which scale proportionally withthe average radiated power, are considered as the transmitpowerdependent part; the circuit power for signal processing,battery backup, site cooling consumption, etc. account forthe transmit-power independent part. The impact of inter-sitedistance and the average number of microcells per macrocellon area power consumption is also addressed. A. Fehskeet al. [23]extended the work to evaluate the potential energy reductionwith varying numbers of microcells and macrocells size toachieve the required spectral efficiency targets under full-loadconditions. It is shown that deployment of micro-cellscan significantly decrease the area power consumptionin the network while still achieving specified area throughputtargets. F. Richter et al. [24], the area power consumption and areaspectral efficiency of homogeneous macrocells, homogeneousmicro-cells, and heterogeneous networks are compared. It isfound that, for higher area throughput targets and higher userdensities, deploying additional microcells is beneficial for EE.

Picocells and femto-cells are also promising deploymentstrategies to provide cost-effective services. Pico-cells andfemto-cells are usually installed within buildings for betterindoor coverage. Indoor pico-cells and femtocells bring receiverscloser to the transmitters and effectively reduce thepenetration loss and path loss; thus, energy consumptioncan be significantly reduced. According to [25], the totalnetwork energy consumption in urban areas for high-datarateuser demand can be reduced by up to 60% with userdeployedresidential pico-cells. Y. Hou et al. [26] is also demonstrated that the achievable gain in system EE with thedeployment of femto-cells in existing macrocells is significantdue to the smaller path loss, lower transmit power, and hencelower energy requirement.

Heterogeneous networks including various types of BSs can enhance network scalability, flexibility and energy efficiency. The density of small cells in heterogeneous networks should be optimized by jointly considering the circuit and transmit power consumption. Distributed antenna system (DAS) can reduce transmit power consumption by moving the antennas closer to users.

Coordinated Multi-Point (CoMP) transmission technology, which divides the traditional BS into a baseband unit (BBU) part and remote radio unit (RRU) parts, has been proposed to expand cell coverage and improve the throughput of cell-edge users. Each RRU is equipped with a transceiver device and can bring the user closer to the antennas of BSs. Thus, CoMP can be used to reduce the system transmission power consumption.

5.2. Relay and Cooperative Communications

Relay and cooperative networks are also promising architecturesand the use ofrelays to exchange information between a BS and a mobile terminal may be an efficientway to improve BS energy efficiency. Relay networks save energy in twoways: reducing path loss due to the shorter transmission rangeand potentially generating less interference due to the lowtransmission power. Relayscan enable important reductions of networkenergy consumption without complicated infrastructuremodifications. These may be deployedin streets or buildings to provide improved signalquality to locations that might otherwise experiencepoor QoS.

The results of A. Radwanet al.[27] show that transmissionwith relays can reduce energy consumption in cellularnetworks as well as power control can further reduceenergy consumption and more energy can be saved.C. Baeet al. [28], thetradeoff between total energy consumption and end-to-endcommunication rate in AWGN relay channels is analyzed,where the impact of the hop number, node locations, allocatedpower and data rate of each hop on EE is also studied.

Different from pure relay systems, each cooperative nodein cooperative communications acts as both an informationsource and a relay. Inherently, energy savings in cooperativenetworks come from the diversity that results from cooperation.

Since a relay node usually has a several-wavelength long distance to the source node, the relay channel experiencesfading conditions independent of that on the direct channelbetween the source and destination. Hence, it can exploit thechannel diversity for potential energy savings.

5.3. Device-to-Device (D2D) Communications

With the growing trend for proximity-based applications,such as peer-to-peer file sharing and local multicasting andadvertising, D2D communications have been proposed toimprove local service flexibility and network throughput, andto support public safety service in case of lack of networkcoverage in 3GPP LTE-Advanced. In D2D communications, proximityusers in cellular networks can transmit data directly to eachother without going through the BS. Due to the physical proximity,D2D communications can potentially provide proximitygain, reuse gain, and hop gain. Thus, D2D communicationscan significantly improve network SE and device EE.

Furthermore, D2D communications can provide more freedomfor D2D users, as they can transmit data in three modes:

- Cellular mode: D2D users are treated as regular cellular users and communicate with each other through the BS in the standard way.
- Dedicated mode: D2D users directly transmit data by using the orthogonal resource of regular cellular users.
- Reusing mode: D2D users directly transmit data by reusing the resource of cellular users.

Through proper mode selection, EE of both devices and thenetwork can be significant improved. D. Wuetal. [29], energy-efficientmode selection and power allocation has been investigated and substantial EE gain has been shown compared with thetraditional transmission without D2D.

VI. ENERGY EFFICIENT TECHNIQUES

To make the network energy efficient, there are various ways like forming energy efficient architectures or using energy efficient radio technologies or obtaining energy efficiency inresource management. This section will thereforebegin by discussing energy harvesting andgreen cellulartechnologies, then move on to discussMassive MIMO(mMIMO), Mm-Waves,small cells and base station hardware improvement withtheir integration in 5G network.

6.1. Energy Harvesting and Green Cellular

Effective usage of renewable energy resources may also help in energy efficiency of a BS. The most important energy resources are solar and wind, which can be used for several reasons like, Reduce amount of Co2; Unreliable grid and Long distance to electricity grid.There are many places, especially in developing countries, where there is a need to provide mobile connectivity but where there is no easy access to the electrical grid. The typical way of providing power to infrastructure in such locations is by means of diesel generators, an inherently costly and complex approach. By improving the energy efficiency of infrastructure, primarily BSs, providing power by means of properly sized solar panels becomes a much more viable option.It is useful as it offers a means of powering electronics where there are no conventional power sources. Solar energy and Simultaneous Wireless Information and Power Transfer (SWIPT) are considered two main sources of energy harvesting.

Recently due to greater demand of energy efficiency in wireless communication, there is a lot of interest of integrating energy harvesting technologies in wireless communication system. One of the upcoming technology of energy harvesting isSimultaneous Wireless Information and Power Transfer (SWIPT)where nodes charge their batteries from electromagnetic radiations.

Strong signals increase power transfer but at the same time they also increase the amount of interference. This technique can be most useful in the case of sensor node or for the upcoming technology of IoT in which the control signals will be used to charge the access point.

The future networks will overcome its problems of path loss with the use of MIMO, small cells and Mm-Waves. The element used for this purpose converts microwave energy to direct current. This is achieved by splitting of the received signal to two orthogonal signals. SWIPT involves modification in the existing communication system [30]. Simultaneous information and power transfer between mobile users and a MIMO BS is represented in figure 4 [30].

For this, the power signal received is split into two signals-one for energy harvesting and other used for information decoding. Several methods are used to achieve this purpose and each of them has advantages and disadvantages.

In antenna switching technique, an antenna element is switched for both decoding and rectifying. This can be used in MIMO systems by using some antennas with strongest channel paths for energy and rest for information.This technique can be used in wireless charging of relay nodes that are power constrained.

In 5G networks, with the coming of mMIMO technology more and more stray RF signals will be available which can be exploited at the relays to harvest power. Therefore, as 5G networks are expected to contain femtocells that will be deployed inside the buildings, they can easily integrate a setup for wireless power transfer for indoor mobile devices.

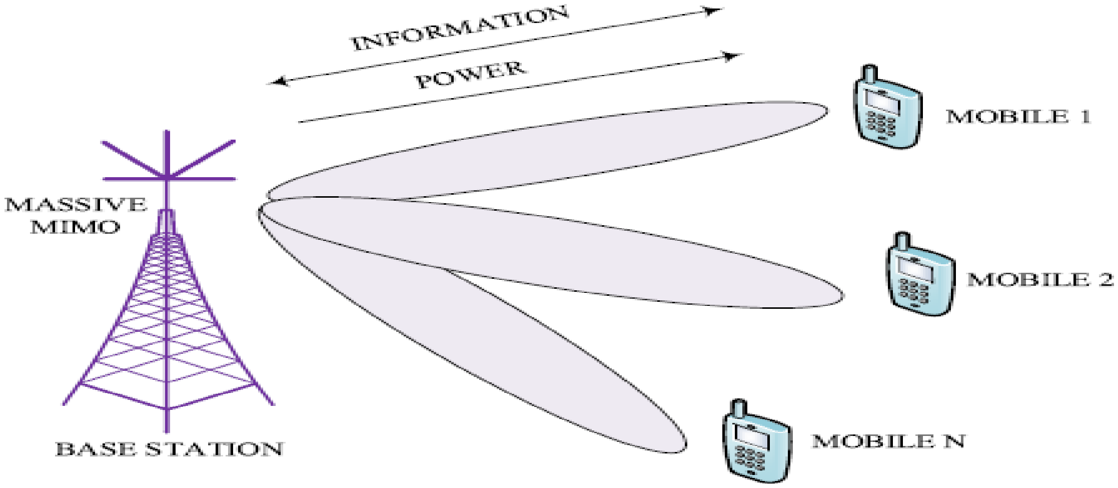

Fig.4: Simultaneous wireless information and power transfer [30].

Recently, a new cellular architecture aiming at minimizing radiation from user terminals is proposed by L. Zhanget al. [31], where it is called ’Green Cellular’ to distinguish itself from traditional architectures by equipping a ’green antenna’ at each transceiver BS. Similar to the principle of femtocells, in green cellular architectures, a mobile user near the green antenna could transmit at a lower transmit power, not only reducing its own power consumption, but also generating less interference to other users. Moreover, the green antennas do not produce any additional radiation, since only uplink traffic is relayed.

Thus, green antennas are suitable for schools, hospitals, etc. Simulation results byB. Hanet al. [32] show a significant reduction, by a factor of 10-10000, in emission power and exposure to radiation. A schematic of the Green Cellular architecture is given in the figure 5 [33].

To have reduced cellular radiation exposure, the green antenna is connected to the network infrastructure via direct point-to-point microwave or wire connection. Currently, green antenna can be set on a sufficient grid and decreasing the mean TX power for MS to any desired value supported by MS, with no additional source of radiation.

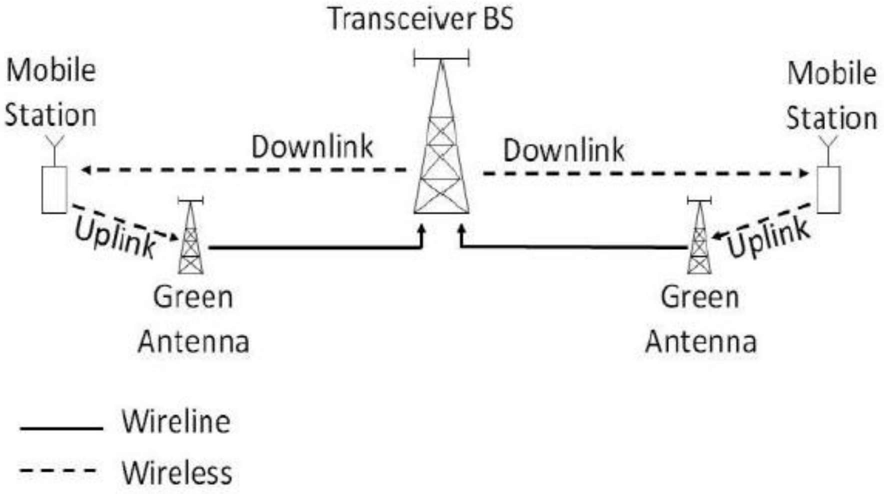

Fig. 5: Transceivers augmented as green antenna [33].

6.2. Millimeter Waves(Mm-Waves)

Mm-Waves are expected to be one of the most promising technology of 5G. It is expected to solve the problem of bandwidth allocation for faster delivery of high quality video and multimedia content. With the growth of wireless industry, the demands of the consumer are increasing day by day which may lead to the problem of congestion of the network by 2020. To overcome this in 5G, the wireless signals are being moved to a higher frequency band operatingat Mm-Wavelength between 30 and 300 GHz on the radio spectrum. The data rates are expected to increase to multi-Gigabit/s in the future. However, with the shift towards Millimeter range, there will be high path loss and signal attenuation leading to limited communication range.

As the Millimeter range wavelength is very small, so it will utilize spatial multiplexing techniques for both transmission and reception. Massive MIMO will play a major role in the Millimeter range. Appropriate signal processing techniques such as adaptive beamforming will enable the transmitting node to direct signal towards the desired receiver. Hence, steerable array antennas will be used in millimeter range spectrum to obtain high data rate and capacity.

Using beamforming by focusing the radiation pattern increases the range of communication as well is expected to have lower power consumption [34]. The use of antenna array with directional transmission between the BS and a mobile reduces signal interference and this accounts for the reduction in energy. When a direct link is established to suppress interference, higher data rates for a given transmission energy level can be obtained. Thus, throughput per unit energy in this case will increase and hence energy efficiency is expected to be improved.

The major advantages of Mm-Wave are better and higher data rates with considerable reduction of energy consumed. Among the Mm-Wave BS(MBS), less congestion is made and easy hand-off is attainable. On the other hand, low reliability and comparatively very high operational cost between the MBS [45].

6.3. Massive MIMO

In the 4G systems, MIMO is the key technology used to increase network capacity. It provides both diversity gain by sending the same signals through different paths between transmitter and receiver antennas as well as multiplexing gain by transmitting independent signals in parallel through spatial channels and this help in reducing energy efficiency.

There is no doubt that MIMO consumes more circuit power due to more number of antennasand it is valuable for longer transmission distances. An adaptive MIMO switching strategy based on channel state information (CSI) to improve energy efficiency is discussed byB. Bougardetal. [35]. However, practically users are equipped with single antenna. So to overcome this limitation virtual MIMO also known as MU-MIMO has been proposed. S. Hussainet al. [36], have been shown that it is more energy efficient than SISO over a particular transmission distance.

In 5G networks, a variant of MIMO is proposed in which a very large number of antennas are employed at the BS called mMIMO. Using this technology, the BS can communicate with multiple users simultaneously in the same frequency band hence providing high multiplexing as well as array gain at the same time.Massive MIMO technology is not only spectrum efficient but energy efficient as well. H. Q. Ngo.et al. [37], have been revealed that transmit power is decreased by the number of antennas at the BS so as to get same data rate like single antenna systems considering CSI is known.

The energy efficiency decreases with increase in spectral efficiency with perfect CSI has been shown byJ. Namet al. [38]. It is obvious that there are a large number of antennas in mMIMO that consume high circuit power hence causing considerable reduction in energy efficiency and a technique of switching off some of the BS antennas is suggested similar to MIMO to improve the energy efficiency of the system. I. Chih-Lin et al.[39] suggest the use of a hybrid analog and digital beamforming RF structure in order to balance the increased circuit power.

By adding more hardware as well, power consumption in mMIMO systems can be considerably decreased, as the dynamic part is decreased, which results in less propagation losses and improved energy efficiency. Improvement in energy efficiency can also be achieved by implementing a network topology combining mMIMO and small cell access points installed in areas with active users with little additional hardware [40].

Transmitted power largely dominates the overall power consumption, deploying more antennas yields a higher energy efficient. On the other hand, system performance bottleneck due to stricter requirements on power consumption and limited physical size [45].

6.4. Small Cells

Small cells are an umbrella term used for operator-controlled, low-powered and low-cost BSs operating in licensed spectrum. They can be densely deployed in order to provide high data rates. Small cells can be of different sizes depending on which they are classified as, Macro cells; Micro cells; Pico cells and Femtocells. The comparison of different cell deployments in terms of their coverage area, output power and capacityare shown in table1.

A trend is towards small cells where circuit power (computation) will become important in addition to transmission power(communication) leading to computation-communication trade-off.

Small cells can have a centralized BS or remote radio heads which can be wired or wireless with core network. They reduce the distance between the user and BS hence also reducing the transmit power required to overcome the path loss especially in the indoor environment hence improving the EE of both uplink and downlink communication.

X. Xu et al. [41], a technique involving separation of control and data signals is investigated for LTE-A networks.There is a Small Cell Access (SCA) point that will be installed on buildings and will communicate with BS. The MSs located inside the building will only need to communicate to the SCA and not to the far located BS hence decreasing both the load and power requirement.

Table.1: Relation between Cell type, Cell Coverage (Cell Radius) and Output Power

Cell Type	Cell Radius	Output Power	No. of Users	Location
Macro cell	8km- 30km	10W-50W	2000	Outdoor
Micro cell	200m- 2km	1W-10W	100-2000	Outdoor/Indoor
Pico cell	100m- 200m	0.25W-1W	30-100	Outdoor/Indoor
Femtocell	10m- 100m	1mW-0.25W	1-30	Indoor

Deployment of small cells requires minimal changes in the current3GPP standards, however can save up to 99 % users' batterypower consumption. The tradeoff between traffic offloadingfrom the macrocell and the energy consumption of the smallcells can be implemented through distributed BS sleepingstrategy.

G. Wuet al.[42], a system framework of cooperative HetNetsis proposed for 5G systems, aiming at balancing the SE, EE,and QoS.Most of the existing works in this topic focus on data signaltransmission in cellular networks and little is known about theimpact of signaling in EE. The concept of separating the controlsignals and the data signals, has been proposed in hyper cellularnetwork for more energy-efficient and flexibleradio access. Furthermore,since small cells in 5G networks will be much denser thanthat in the 4G networks for hotspot coverage, interferencemanagement, while considering the SE and EE target, willbe a challenging issue.

6.5. Base Station (BS)Hardware Improvement

BS hardware improvement is one way to reduce energy consumption. This is achieved by addressing the part that consumes more power in a BS, that is, the power amplifier.

As mentioned before in Section. 2, the radio consumes most of the BS's power consumption. The PA consumes more than 55% of energy and approximately 80-90% goes to waste due to the PA requiring an operating cost and additional energy, and the best solution for this is to use the switch mode power amplifier to increase the operating frequencies on mobile systems wireless. Since some technologies related to level efficiency of modern amplifiers have reached their limits, PAs based on some special architecture such as digital pre-distorted, Doherty architecture and GaN (Aluminum Gallium Nitride) based amplifiers seems to be more efficient by pushing the power efficiency levels to over 50% [43].

It is therefore essential to obtain a flexible PA architectural design capabilities to adapt to desired outputs according to signal fluctuations. In recent architecture, mobile terminals and BSs continuously transmit pilot signals while LTE-Advanced transmit data at higher rates. When there is no signal for transmission, then switching off the transceiver is a way to save power. The LTE standards utilized this by a power saving protocol like DTX and DRX modes in mobile handsets. DTX and DRX save power by temporarily switching off the device while maintaining connection with little throughputand reducing site cooling costs.Additionalefficiency can be achieved by shifting to the switch-mode PAs rather thantraditional RF amplifiers. Switch-mode PAs generate very little power as heat, resultingin a highly efficient power supply. The total component efficiency of such devices can reach around 70% [44].

For a number of years, there has been interest in an efficient design of wireless network with prolonged battery lifespan for mobile terminals and sensor nodes. Climate change and environmental impacts due to emissions of warming have changed the focus of energy efficient of wireless networks.

Table.2: Summarizes the advantages and disadvantages of energy efficient techniques.

EE Technologies	**Advantages**	**Disadvantages**
Energy Harvesting and Green Cellular	1. Improve energy efficiency of a BS. 2. Reduce amount of Co2 and exposure to radiation. 3. SWIPT are used for charging batteries of nodes and sensor of IoT from electromagnetic radiations.	SWIPT may increase interference.
Mm-Waves	1. Using beamforming increases range of communication as well as lower power consumption. 2. Using of antenna array with directional transmission between the BS and a mobile reduces signal interference and this accounts for the reduction in energy consumption. 3. Higher data rates with considerable reduction of energy consumed. 4. Among the BS, less congestion is made and easy hand-off is attainable.	High path loss and signal attenuation leading to limited communication range.
Small Cells	1.Provide high data rates and low-powered and low-cost BSs operating in licensed spectrum. 2. Small cells in 5G networks will be denser for hotspot coverage and interference management. 3.They reduce distance between user and BS and reducing the transmit power required to overcome the pathloss especially in the indoor environment hence improving the EE of both uplink and downlink communication. 4.They can save up to 99 % users' battery power consumption.	Increase cost of implementation.
Massive MIMO	1. Transmitted power largely dominates the overall power consumption, deploying more antennas yields a higher energy efficient. 2.Technique of switching off some of the BS antennas in idle case are used to improve the energy efficiency of the system. 3. Hybrid of analog and digital beamforming RF structure are useful to balance the increased circuit power. 4.Combining mMIMO and small cell access points improve energy efficiency.	1.A large number of antennas in mMIMO consume high circuit power. 2.System performance bottleneck due to limited physical size.
BS Hardware Improvement	1. DTX and DRX save power by temporarily switching off the device while maintaining connection with little throughput and reducing site cooling costs. 2.Switch-mode PAs generate very little power as heat, resulting in a highly efficient power supply.	Power consumption of BS are high and requiring high operating cost.

VII. ENERGY EFFICIENT ARCTECTURE

In present wireless network architecture, a centrally located BS is required by a mobile user to communicate whether present indoor or outdoor. When indoor users communicate using the outdoor BS it results in high penetration loss which leads to low spectral as well as energy efficiency of the network.To overcome this challenge, separate outdoor and indoor setups have come into existence. This idea will be supported with the help of mMIMO technology already discussed in previous section. Next generation architectures are expected to support various heterogeneous technologies. Each building is expected to have its own access point which will support indoor users and will communicate to the outdoor BS.Along with providing high connectivity and data rate, it will also be an energy efficient setup with the only disadvantage of incurring initial infrastructure cost.

The 5G networks need an urgent improvement in energy efficiency. This can be achieved by integrating the conventionally known techniques of power optimization using relays in the 5G network. The architecture also includes the concepts of SWIPT, mMIMO and cloud- RAN for improving EE in the next generation network.

The next generation networks are expected to have BS radius of about few hundred meters and small cell radius of approximately 40 meters. We have assumedsome scenarios in the architecture. Firstly, the BS communicates directly with the MS which are in its coverage area and are located outdoors and hence suffering with small path loss due to good channel conditions. Relays are used for MS which suffer from higher path loss and hence require more power of the transmitting BS. This leads us to next scenario in which BS communicates with a MS through a relay hence consuming small power and making the network energy efficient. The transmitting power of a relay as well as BS can be minimized by optimum Relay Selection schemes. The Relay with optimum power for a specific destination is selected and used for transmission. These scenarios already exist, but in our architecture, they are used only when the user is located outdoors. We suggest the other two scenarios for next generation networks to make them energy efficient. The indoor users as discussed do not directly communicate with the BS. Instead they directly communicate with the SCA point located in each building which in turn communicates with the BS. But there are certain situations when there is high path loss between the BS and the SCA as well. So to maintain the required QoS and SNR along with satisfying the power constraints to make the network energy efficient, it is required to introduce a relay between BS and SCA. So, the last scenario we have proposed is when the BS communicates with the relay which then sends the data to the specific SCA point of the building where MS is located indoors.

The BS in the next generation network is expected to support mMIMO and SWIPT technology in the suggestedarchitectureas shown in figure 6. All the communication will take place in the Mm-Wave.

Future IMT will require more flexible network nodes that are configurable based on the Software-Defined Networking (SDN) architecture and network function virtualization (NFV) for optimal processing the node functions and improving the operational efficiency of network. SDN use the process ofdecoupling control and data planes toenable superior programmability, adaptability, and flexibilitytowards network architectures [46].

Featuring centralized and collaborative system operation, the cloud RAN (C-RAN) encompasses the baseband and higher layer processing resources to form a pool so that these resources can be managed and allocated dynamically on demand, while the radio units and antenna are deployed in a distributed manner. C-RAN mainly aims at reducing the BS sites by using centralized processing, BS being the highest consumer of power in a wireless network. It also aims at supporting high coverage by use of small cells that will be connected to the C-RAN and reducing the transmission distance, which will eventually lead to lower power consumption and increase UE stand-by time. It can be easily and selectively switched off to save power during no load hour.

Hence, C-RAN is expected to play a major role in energy saving.The radio access network (RAN) architecture should support a wide range of options for inter-cell coordination schemes.

Moreover, a concept of Self-Organizing Networks (SONs) is introduced in 3GPPstandard to add network management to improve network performance and flexibilityas well as to reduce cost.

Different use cases ofSON, e.g., cell outagemanagement, load balancing etc., are among theinitial ones to explore the performance of self-organizing techniques.The advanced SON technology is one example solution to enable operators to improve the OPEX efficiency of the multi-RAT and multi-layer network, while satisfying the increasing throughput requirement of subscriber.

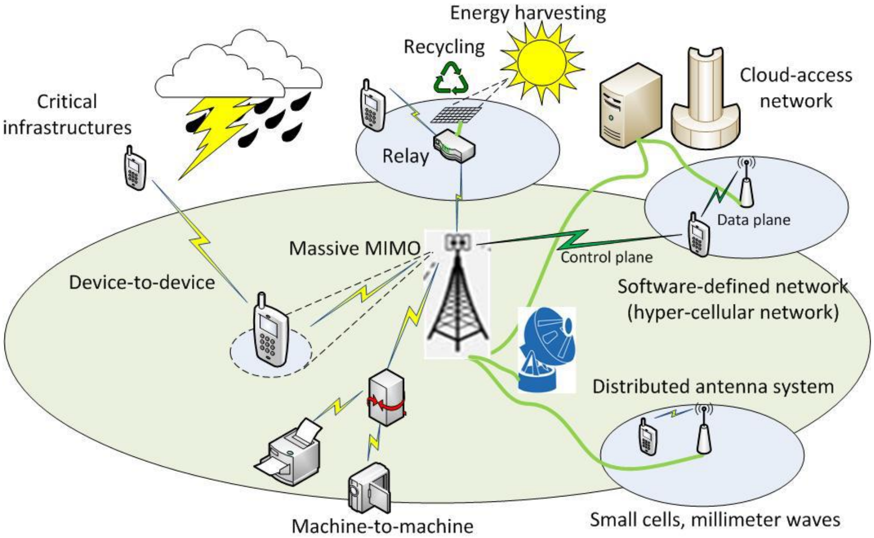

Fig. 6: Revolutionarytechnologiesfor5G

VIII. FUTURE RESEARCH CHALLENGES

The transition from 4G to 5G introduces several transformational challenges, which must be managed to fully realize the 5G vision. There are challenges faced with the new technologies enabling 5G and the integration of them to provide services in different application scenarios. To address these challenges, a rigorous change in the design of cellular architecture are needed. We also need to meet 5G system performance requirements such, stringent latency, network scalability, green communications and very long battery life. It is a challenge to satisfy these requirements and minimize costs at the same time [47].

The 5G networks are expected to meet the needsof the consumers along with providing a solution for greencommunication. Use of new techniques such as SWIPT, mMIMO, Mm-Wave as well as continued use of small cellsand relays in the next generation networks will impose newresearch challenges.

SWIPT is a promising technology for future but has unsatisfactoryresults for longer distances due to high path loss.Spatial diversity can be used to overcome this path loss.Thus, use of mMIMO along with SWIPT need to beinvestigated for better results. In addition, efficient circuit modulesneed to be developed which can reduce the power splittingloss as well as cost of the hardware.

The EE of mMIMO network with full duplex relaychannel needs to be studied. The EE of mMIMO inmultiple cell scenario needs to be investigated to eliminatethe effect of interference. The tradeoffbetween power consumed by hardware and power savingof the network by using mMIMO with beamforming inthe millimeter range also needs to be investigated along withthe overall energy efficiency of the network.

Further research also needs tobe carried out for efficient implementation of BS sleep modes to save maximum possible power. The powerallocation strategy by BS to small cells and its impacton the energy efficiency of the network needs investigation.

Energy efficient resource management helps in savinghuge amount of power. The handoff and coverage issuesbetween neighboring small cells and its impact on EE needsto be further estimated. The collaboration between neighboring cells should befurther studied since the cell mode switching changes thecoverage and handoff issues. The effect of these changeson EE should be evaluated.The QoS requirement of a particularapplication and time varying channel condition and its relationwith EE needs to be developed.

The selection of relays by combining various relayselection policies for a particular application and its impact onEE needs to be estimated. Also, the tradeoff between EE andacquiring CSI for relay selection needs to be further analyzed.

Although much work on energy efficient network deploymentstrategies has been done, current results are still quitepreliminary and some challenges remain to be investigated.The power control strategy and efficient algorithm in D2Dcommunication to minimize interference at the same timeensuring optimum SNR needs to be developed.

IX. CONCLUSION

This paper has presented a comprehensive survey on recentadvances in EE wireless networks in the past decade andidentified emerging challenges for potential applications in5G cellular networks. The methodology in analyzing the EErelationship with other factors has been summarized, and energy-efficientresource allocation has been addressed from the optimizationperspective. Many open issues in designing energy-efficient5G systems, such as mMIMO,small cells and heterogeneous networks, distributed antennas, Relay and multi-hop cellular, D2D communication etc.; as well as radio and network resource management schemes such as dynamic power saving, traffic balancing among multiple RATs coordination, discontinuous transmission (DTX) havebeen provided.We have analyzed the trends in the field of wireless communications in the last decade whichindicated a shift towards pursuing green communication for the next generation network.

Previous research shows that optimized energy-efficientdesign (including network deployment, transmission schemeand resource management) could significantly reduce the energyconsumption of the entire network. Nevertheless, currentresearch results are still quite preliminary and many challengesremain. In summary, the main findings of this paper are as follows:

The power consumption of the current network design and operation is mostly independent of the traffic load. This highlights the great potential for energy savings by improving the energy efficiency of BSs at low load.

A well-deployed heterogeneous network will not only bringbetter performance on coverage and capacity but alsohigher energy-efficiency. For example, the energy-efficientlayout of micro cells, picocells and CoMP technology can be used to reduce the system transmission power consumptionas well as the newcellular architecture dubbed ’Green Cellular’ have shown significant energy-efficiency improvement.

Massive MIMO technology is not only spectrum efficient but energy efficient as welland CSI have shown considerableenergy saving.A system model for EE improvement with the use of relay selectionand cooperative communications has also been described along with a comparison of various algorithms used for EE in relay based environments.

Based on the survey of the techniques available, an energy efficient architecture for 5G networks has been proposed using relays as will be present in the next generation along with small cells in millimeter range wavelength. EE techniques such as mMIMO, C-RAN and power harvesting have alsobeen incorporated into the proposed architecture. The main focus lies on use of relay for the next generation networks as well as small cells and their role in improving energy efficiency. Various challenges for future research for improving EE of wireless network have also been discussed.

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