

Received March 17, 2016, accepted March 29, 2016, date of publication April 7, 2016, date of current version April 15, 2016.

Digital Object Identifier 10.1109/ACCESS.2016.2549641

Power Optimization in 5G Networks: A Step Towards GrEEn Communication

AKSHITA ABROL, (Student Member, IEEE), AND RAKESH KUMAR JHA, (Senior Member, IEEE)

School of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Jammu and Kashmir 182320, India

Corresponding author: R. K. Jha (jharakesh.45@gmail.com)

ABSTRACT In the present scenario, an energy efficiency has become a matter of prime importance for wireless networks. To meet the demands of an increased capacity, an improved data rate, and a better quality of the service of the next-generation networks, there is a need to adopt energy-efficient architectures. Along with these requirements, it is also our social responsibility to reduce the carbon footprint by reducing the power consumption in a wireless network. Hence, a green communication is an urgent need. In this paper, we have surveyed various techniques for the power optimization of the upcoming 5G networks. The primary focus is on the use of relays and small cells to improve the energy efficiency of the network. We have discussed the various scenarios of relaying for the next-generation networks. Along with this, the importance of simultaneous wireless power and information transfer, massive multiple input multiple output, and millimeter waves has been analyzed for 5G networks.

INDEX TERMS 5G, C-RAN, energy efficiency, green communication, relay, small cells, SWIPT.

I. INTRODUCTION

With the rapid growth and evolution of information and communication technology, energy consumption is also growing at a very fast rate. It has also been reported mobile operators are among the top energy consumers [1]. The energy consumption is growing even more with the deployment of 4G systems worldwide. Thus, there is an urgent need to shift from pursuing high capacity and spectral efficiency to energy efficient design. By reducing power consumption of wireless networks we can improve their energy efficiency. The energy efficiency of 5G networks is expected to be increased 100x times from 1000 mW/Mbps/sec in IMT-2000 to 10 mW/Mbps/sec in IMT-Advance and future IMT [2].

Energy efficiency is becoming a matter of great concern in the telecommunications community due to a number of reasons such as huge data rate requirements, increasing price of energy, ecological impact of carbon, pressure and social responsibility for fighting climate change [3]. This has led to joint academic and industrial research for developing energy-saving techniques like 'green radio' project [4], the EARTH project [5] and so on. Research is also being carried out on the next-generation wireless networks including the third generation partnership project's (3GPP) long term evolution-advanced (LTE-A) and IEEE 802.16 standard [6] to focus on relaying techniques between the Base station and the Mobile stations as a means to reduce the power consumption as

well as to save the operator from incurring the huge cost of deployment of a new base station.

From the users' perspective as well, energy efficiency is the need of the hour. The battery capacity is increasing only 1.5x per decade and has always been a concern for the user. In the future networks, there will be unbounded access to information and sharing of data everywhere and every time with the ever increasing number of energy hungry applications. So, to satisfy users' demand of battery life, energy efficiency in wireless communication is imperative. Another factor under consideration is the health concern of the user. High power radiated by handsets while in use tend to harm the user in close proximity. Hence, shifting towards more energy efficient techniques becomes all the more important.

The need for adopting green communication has been realized worldwide. There is a focus on following holistic approach for power optimization. The next generation architectures focus on developing new technology, cell deployment strategies and resource allocation policies to improve the energy efficiency of a wireless communication network. The basic architecture which has been used in the past for decreasing the power consumption of the network consists of relays as a primary agent of reducing the path loss and hence improving its energy efficiency. The architecture is shown in Figure 1 which considers both line of sight and non-line of sight paths between the source and destination.

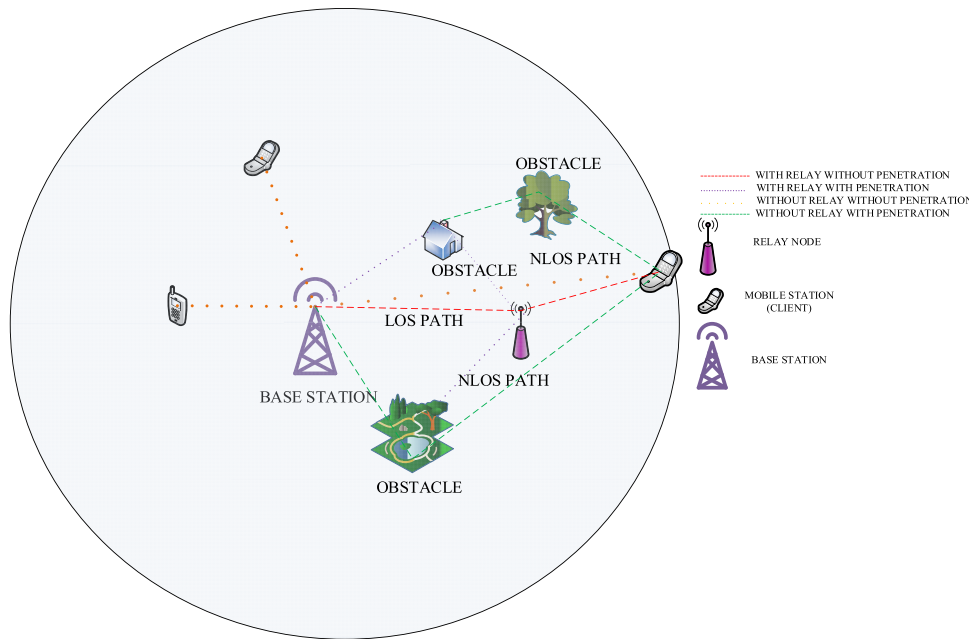


FIGURE 1. Basic Architecture for energy efficiency.

A. CONTRIBUTIONS

This paper addresses various energy issues as well as discusses various trends in power optimization in the last decade. It provides a detailed analysis of various techniques which will be adopted in the 5G networks to improve the energy efficiency of the network. It also discusses the need of choosing an appropriate energy efficiency metric. In this paper, we have proposed an architecture using the traditionally known concept of relays and its integration with the current 5G network comprising of small cells. The concepts of new technologies such as SWIPT, C-RAN and massive MIMO in millimetre range communication have also been incorporated in our architecture. A system model for energy efficient relay selection has also been discussed. The focus of this paper is to power optimize the next generation network and promote the concept of green communication.

Specifically, in section II we have discussed the evolution of wireless communication with focus on various power trends till date. In the next section III, we have discussed the work that has been done in the area of wireless communication to improve energy efficiency in the last decade. In section IV, we have defined the meaning of energy efficiency as well as the importance of choosing the correct energy efficiency metric and its need in present scenario. In section V, we have focused our attention on the following areas to improve the energy efficiency which include EE in massive multiple-input multiple-output, EE improvement by use of millimeter waves with directional beamforming antennas, EE improvement by use of small cells, EE improvement by using relays and new techniques to harvest energy from RF signal (SWIPT). We have given our prime attention to relays and the proposed an architecture integrating

all the techniques for an energy efficient 5G network in section VI. The importance of power optimization in green communication along with life cycle assessment of a mobile phone is discussed in section VII. Section VIII discusses the various challenges which need to be addressed for energy efficiency in 5G networks and the final conclusion is drawn in section IX.

A list of current research projects in the field of energy efficiency improvement is given in the appendix along with the standardization activity and a list of all the abbreviations used in this paper.

II. EVOLUTION OF WIRELESS COMMUNICATION

The first communication device using electricity, i.e., the telegraph was invented by S. Morse in 1838. It could also be used to transmit human speech. In the 1850's, Maxwell foresaw that energy could be transported wireless which was later demonstrated by Hertz in 1888. A. G. Bell had already invented the telephone in 1876. Wireless telegraphy followed for which the transmitter had to use extremely high power over the wireless channel to compensate for path loss over distance. The electron tube amplifier by de Forest in 1915 compensated for this path loss. It enabled radio broadcasting which was later followed by TV broadcasting. The electron tube was subsequently replaced by low-power transistor. Soon after that wireless communication advanced to pervasive mobile telephones which has transformed the style in which our society runs.

A. FIRST GENERATION (1G)

In early 1980's, analog cellular systems appeared, referred to as the first-generation (1G) systems, such as the Nordic Mobile Telephone, the Advance Mobile Phone Service and

TABLE 1. Power trends from 1G to 5G.

Technology	Frequency Band	Power Density (Watt/M ²)	MS Power Level	BS Power Level	Methods of Power Optimization
1G	800 MHz	4.0	Low	Low	Shift from wired to wireless. Modulation techniques such as SSB-FM used to save power.
2G	850/900/1800/1900 MHz	4.5-9.0	GSM850/900: 33dBm GSM1800/1900: 24-39dBm	Macro: 46dBm Micro BTS: 14-32dBm	Sleep mode of BS and low powered radio signals as compared to 1G used.
3G	800/850/900/1800/1900/2100 MHz	4.5-10	21-33dBm	24-38dBm	Sleep Mode of BS and use of relays.
4G	1.8GHz, 2.6GHz	10	23dBm	43-48dBm	PAPR minimization in OFDMA and SC-FDMA, BS energy saving, use of relays, small cells.
5G	30-300GHz	10	High	High	Use of small cells, relays with SCA and D2D communication, SWIPT, C-RAN.

the Total Access Communication System. It had data rate upto 2.4kbps but had many disadvantages. Since it was first system to be designed major concern was ensuring wireless connectivity and coverage and no focus was given to power optimization of the network.

B. SECOND GENERATION (2G)

After about a decade the early digital cellular systems followed, referred to as the second-generation (2G) systems. The 2G systems were mainly designed for voice along with power control approaches that provided a fixed data rate of about 64kbps maintaining certain Quality of Service. It also provides services like Short Message Service and e-mail. Main 2G standards were Global System for Mobile Communications (GSM), IS-95 and IS-136 [7]. The 2G mobile handsets had longer battery life because of low power radio signals.

Then came 2.5G which used 2G system framework but it applied packet switching along with circuit switching. It provided data rate up to 144kbps. The main 2.5G technologies were General Packet Radio Service, Enhanced Data Rate for GSM Evolution, and Code Division Multiple Access 2000 [6]. The power levels were same as 2G.

C. THIRD GENERATION (3G)

In late 2000, 3G systems appeared which provided transmission rate upto 2Mbps along with improvement in QoS. 3G is based on wideband CDMA standard, called International Mobile Telecommunications 2000, specified by the International Telecommunication Union. One such 3G standard is Universal Mobile Telecommunications System which is a successor to GSM and standardized by the 3rd Generation Partnership Project (3GPP) [8]. Other services provided by 3G included global roaming and improved voice quality. The major disadvantage for 3G mobile handsets was that they required more power than most 2G models.

D. FOURTH GENERATION (4G)

After another decade ITU Radio Communications group (ITU-R) specified the IMT-Advanced requirements for 4G standards. 4G is generally referred to as the descendant of the 3G and 2G standards. 3rd Generation Partnership Project (3GPP) is presently standardizing Long Term Evolution Advanced (LTE-A) as forthcoming 4G standard. Services like voice, data and multimedia will be provided to subscribers on every time and everywhere basis and at high data rates as compared to earlier generations. Applications such as Multimedia Messaging Service, Digital Video Broadcasting, and video chat, High Definition TV content and mobile TV will also be accessible to users [9].

In the emerging such as the 3GPP LTE-A standard and the IEEE 802.16j standard, the concept of multi hop in-band and out-band relays has been introduced which will help in increasing the coverage area as well as making the network more energy efficient [10]. The main disadvantage of 4G systems is the use of cell-specific reference signals (CRS) which decrease the energy efficiency of the network by causing excessive overhead.

E. FIFTH GENERATION (5G)

The 4G network soon will be replaced by the next generation 5G network to meet the increasing demand for high data rate. To meet the demand of the subscribers, improvement in the energy efficiency of the next generation networks is imperative. Green communication will play a major role in this. 5G includes techniques like Massive MIMO, Beam division multiple access, D2D communication and use of multiple radio access technologies.

The power requirement of the network increases with the frequency in use. The prescribed safe RF exposure limit according to ICNIRP guidelines expressed in terms of power density (watt per square meter) is $f/200$ where f is the frequency in MHz [11]. The Table 1 shows the comparison

of power usage in different generations along with the various techniques which are used to make the network power efficient.

To maximize the efficiency upcoming systems, the scheduling of time and frequency resources needs to be coordinated with the power optimization techniques [8]. The future networks providing even more data rate will require more such power saving techniques.

III. RESEARCH TRENDS IN LAST DECADE

The emphasis on study of energy-efficient communication started about a decade ago. At present, the rapid increase in communication technology has led to demand for high data rate applications making energy efficiency all the more important [12]. Various research projects such as EARTH [5], [13], eWIN [14], [15], OPERA-Net [16], [17] and Green Radio [18] have been launched in the last decade with the aim of making wireless communication networks energy efficient. Project EARTH proved to be a great success. It was committed to the development of a new generation of energy efficient equipment, deployment strategies and network management solutions. In [19], use of multiple radio access technologies is proposed by EARTH to overcome the variation of load. OPERA-Net proposed energy saving by reducing cell size and implementing sleep modes. From time to time, sleeping time of the base station, cell size, adaptive load variation algorithms, relay and cooperative communication, resource allocation techniques and various radio access techniques have helped in making wireless communication energy efficient. A strategy to switch off inactive cells in low traffic environment using analytical model is proposed in [20]. The shift in trend to pursue green communication [21] in next generation wireless network is represented in figure 2.

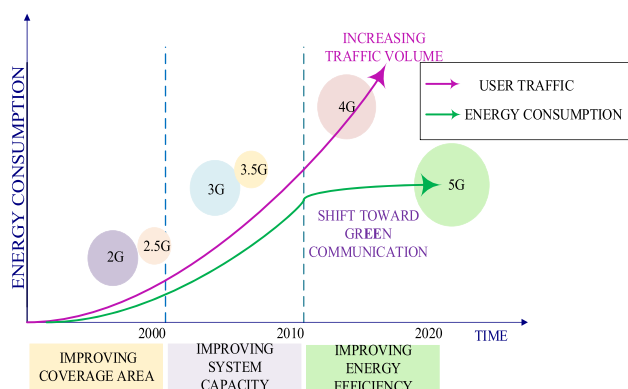


FIGURE 2. Shift toward green communication.

In the last decade, network deployment strategies have gained much attention including the focus on optimal cell size to improve energy efficiency [12], [22], [23]. Using picocells [24] and femtocells [25]–[27] decrease path loss and improve energy efficiency of the network. In [28], a new cellular architecture Green Cellular is proposed to minimize radiation from user terminals. Relays and cooperative

communications have also gained much attention in the past decade for reducing the power consumption. Lin *et al.* [29] proposes design routing algorithms to optimally utilize the available energy in heterogeneous environment.

BS energy saving has also gathered much attention in recent past. A lot of energy is wasted due to variation in traffic loads at the base stations. To overcome this, China Mobile deployed dynamic power save to reduce power consumption by 27% [30]. In [31], traffic aware base station sleeping is proposed. Energy aware management of UMTS access network based on instantaneous traffic intensity is proposed in [32]. In [33], a scalable BS switching strategy along with the use cooperative communications and power control to extend the network coverage to the service areas of switched-off base stations is proposed.

Adaptive MIMO mode switching based on transmission distance [34], rate [35], as well as channel state information [36] is being used to improve energy efficiency. Cross layer optimisation is another prominent approach to decrease energy consumption [37], [38]. Energy efficient resource allocation in OFDMA system with relays has been a topic of research. Hence, in the last decade, resource allocation, heterogeneous network deployment, transmission scheme optimisation and developing energy efficient algorithms have attained much attention.

IV. ENERGY EFFICIENCY METRIC

With the evolution of communication technology, a corresponding requirement for optimization in energy consumption is also growing. According to a survey the mobile operators are amongst the top energy consumers as well as their consumption is growing at a very fast rate especially with the deployment of 4G technology. The base station consumes a large part of the energy generating a large amount of electricity bill. Thus, not only from the operator's but also from the consumer's point of view, obtaining energy efficiency has significant economic benefits. It also has great ecological benefits and represents social responsibility in fighting climate change [39]. So, there is an urgent need to pursue energy efficiency along with optimal capacity and spectral efficiency when designing a wireless networks.

From the user's point of view as well the energy efficiency in wireless communication is imperative. The need for energy efficient transmission originates from energy constrained networks like ad-hoc networks where wireless devices are battery powered so energy consumption must be minimized [40]. Thus, the cellular systems must be energy efficient, especially with the recent growing demand in mobile multimedia communication which has made the battery constraint a major issue. This has motivated optimization of energy for the use of mobile devices.

With the emergence of 5G technology the importance of energy efficiency for wireless networks has been realized even more. The major concern is to improve EE without compromising on user experience. Deciding the adequate energy efficiency metric is of prime importance before analysing

a power optimised network. Energy Efficiency conventionally is defined as the measure of number of bits transmitted per joule of energy consumed [41]. This can be defined as the system throughput for unit energy consumption [42]–[45]. But all transmitted data is not real information so should not be included in throughput. EE can be considered from two point of views [2].

- Network EE: It is defined as the quantity of information bits transmitted to or received from users per unit of energy consumption of RAN in bit/Joule.
- Device EE: It is defined as the quantity of information bits per unit of energy consumption of the communication module in bit/Joule.

From [46], the energy consumed depends on the type of the base station and has two parts: static and dynamic. For a macrocell base station, the static part dominates whereas for microcell base station, the dynamic part dominates the energy consumption. The tradeoff between circuit and transmit energy for overall EE is shown in [37]. Traditional power optimization techniques consider only transmit power but it only makes sense if transmit power has much larger proportion in total power consumption. This is possible only for longer transmission distance [34], [47] as well as in case of high data rate applications [35]. Hence, we gather that a good EE metric must consider circuit as well as transmission power and saving in one of them must not be counteracted by increase in another for obtaining an energy efficient network. In the current scenario there can be various definitions of Energy Efficiency depending upon the application area which are discussed below:-

- Information Theory: EE is minimizing the energy consumed per bit.
- Sensor Networks: EE is prolonging the network lifetime.
- Cellular Networks: EE is prolonging the standby time of MS and maximising EE under QoS constraint.

In this paper, we concentrate on EE improvement in cellular networks and for this various techniques have been discussed in the next section.

V. ENERGY EFFICIENT TECHNIQUES

To make the network energy efficient, we have various ways like forming energy efficient architectures or using energy efficient radio technologies or obtaining energy efficiency in resource management. Some of these techniques have been listed in the form of a Table 2.

The techniques in the table have been discussed further and further we concentrate our attention on power optimization using relays and their integration with 5G network.

A. SIMULTANEOUS WIRELESS INFORMATION AND POWER TRANSFER (SWIPT)

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. The most upcoming technology is WPT where nodes charge their batteries from electromagnetic radiations.

TABLE 2. Techniques for energy efficiency.

1. Energy-Efficient Architectures: Optimization of cell size: large vs small cell deployment Overlay source : microcell, picocell or femtocell Relay and cooperative communications
2. Energy-Efficient Resource Management: Joint power and resource allocation SISO vs. MIMO with packet scheduling
3. Energy-Efficient Radio Technologies: Heterogeneous network deployment (Multi-RAT) SWIPT Millimeter wavelength

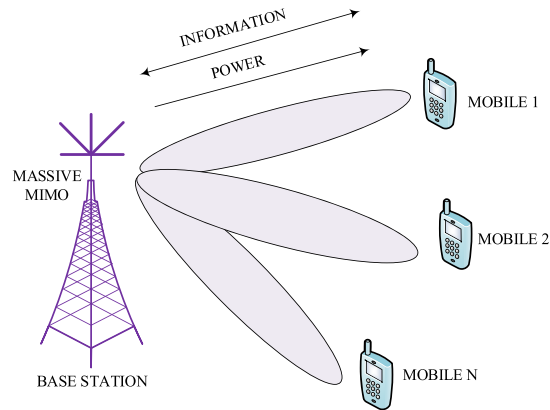


FIGURE 3. Simultaneous wireless information and power transfer.

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 Internet of Things 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 is a Rectenna which 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 [48]. There can be three scenarios where we use SWIPT:

- Near field scenario: Power is transferred using inductor or capacitor coupling and upto tenths of watt can be transferred with a range of 1 m.
- Far field Scenario: Power is transferred using directive power beaming with directive antennas upto mW and range of several meters.
- Far field low power scenario: Power is transferred with RF power scavenging upto micro Watts with range of several km.

Simultaneous information and power transfer between mobile users and a MIMO base station is represented in figure 3.

Now we concentrate ourselves on the far field scenario. For this the power signal received is split into

two signals—one for energy harvesting and other used for information decoding [49]. Several methods are used to achieve this which are as follows:-

1. **Time Switching:** This is not a simultaneous processing technique as in one time slot RF signal is used either for information or for power transfer. It requires time synchronization.
2. **Power Splitting:** In this an RF signal is separated into two streams of different power levels using a power splitter. It is more complex and is used for critical information transfer.
3. **Antenna Switching:** In this technique an antenna element is switched for both decoding and rectifying. This can be used in MIMO systems. It uses some antennas with strongest channel paths for energy and rest for information.
4. **Spatial Switching:** This technique exploits multiple degrees of freedom of interference channel. The MIMO channel is transformed into parallel eigen value channels that can be used for either power or information transfer.

This technique can be used in wireless charging of relay nodes which are power constrained. In 5G networks, with the coming of Massive MIMO technology more and more stray RF signals will be available which can be harnessed at the relays to harvest power. SWIPT as discussed is more successful in the near field scenario. So, as 5G networks are expected to contain Femtocells (discussed in next section) which will be deployed inside the buildings, they can easily integrate a setup for wireless power transfer for indoor mobile devices. The only concern in this regard will be keeping the emissions below the set standards.

B. MILLIMETER WAVES

Millimeter 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 operating at millimeter wavelength between 30 and 300 GHz on the radio spectrum. The data rates are expected to increase to multi gigabit per second 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 [50]. Appropriate signal processing techniques such as adaptive beamforming will enable the transmitting node to direct signal towards the desired receiver [51]. 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 [52]. The use of antenna array with directional transmission between the base station 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.

C. SMALL CELLS

Small cells is an umbrella term used for operator-controlled, low-powered and low-cost base stations 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:-

- Femto cells (up to 100 m)
- Pico cells (up to 200 m)
- Micro cells (up to 500 m)

The graph in figure 4 shows the comparison of different cell deployments in terms of their coverage area and capacity.

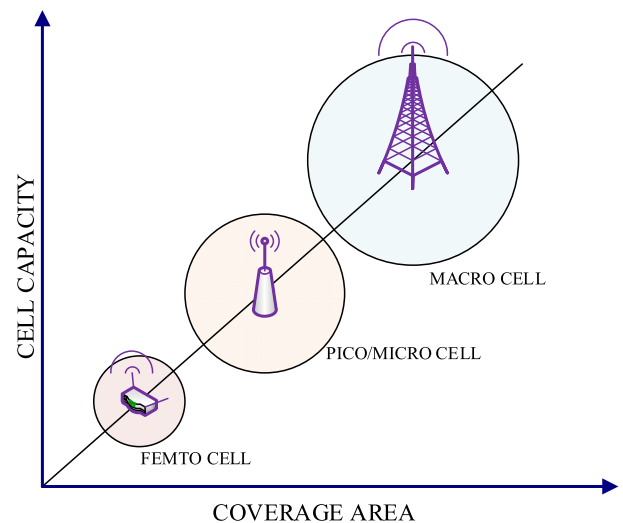


FIGURE 4. Cell capacity vs coverage area.

Small cells can have a centralized base station 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 pathloss especially in the indoor environment hence improving the Energy Efficiency of both uplink and downlink communication.

In [53], inter frequency discovery techniques for small cells were proposed which greatly helped in improving energy efficiency and hence saving users' battery. Another technique involving separation of control and data signals is suggested in [54] and has been further investigated for LTE-A networks in [55]. There are three basic access policies as in figure 5 which can be used in each cell. These are described below:-

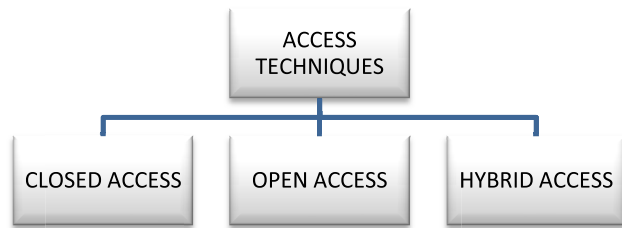


FIGURE 5. Types of access policies.

- Closed access: In this scheme only the users present in a closed subscriber group can connect with each other.
- Open access: In this scheme all users can connect with each other.
- Hybrid access: In this scheme all users can connect with each other as well as priority is given to specific users.

Out of these closed access consumes the least amount of energy.

There is a Small Cell Access point which will be installed on buildings and will communicate with Base Station. The Mobile Stations located inside the building will only need to communicate to the SCA and not to the far located base station hence decreasing both the load and power requirement. Deployment of Small cells requires minimum changes in the current standard and can save a lot of user's battery consumption. The trade-off between traffic offloading and energy consumption can be implemented through BS sleeping strategy.

D. 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. Both also help in reducing energy efficiency. Liu *et al.* [56] studies the impact of both these gains on energy efficiency using MIMO transmission. In [34], the relation between transmission distance and energy consumption for SISO, SIMO and MIMO is compared. There is no doubt that MIMO consumes more circuit power due to more number of antennas. So it is beneficial for longer transmission distances. In [35], a tradeoff between circuit and transmission power to obtain higher energy efficiency in MIMO systems is discussed. An adaptive MIMO switching strategy based on channel state information to improve energy efficiency is discussed in [36]. But practically users are equipped with single antenna. So to overcome this limitation virtual MIMO also known as MU-MIMO has been proposed. In [57] and [58], it has been shown that it is more energy efficient than SISO over a particular transmission distance. In [59], an algorithm is proposed for a virtual MIMO system using smart antennas for energy efficiency improvement. For supporting 8×8 MIMO, reference signals are used to minimize performance degradation due to errors in channel estimation. LTE employs constant reference signals for this purpose. However, its main

disadvantage is that it causes too much overhead and leads to decrease in the energy efficiency of the network [60]. For adaptive multi-antenna transmission, two additional reference signals have been specified in LTE-A as discussed in [61] and shown in figure 6.

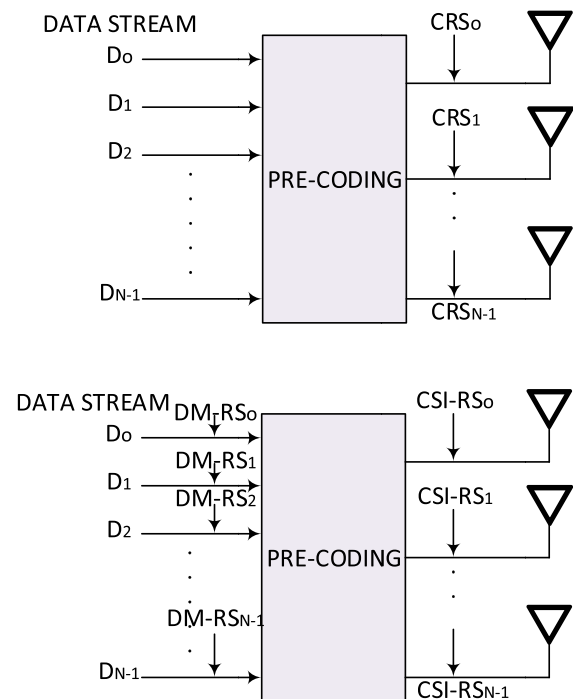


FIGURE 6. CRS based Vs CSI/DM based precoding.

- Channel state information reference signal (CSI-RS): It is cell specific and used for estimation of channel quality similar to CRS only with lesser overhead as it is transmitted with much less frequency.
- UE-specific demodulation reference signal (DM-RS): it is used for demodulating data at specific UE and is precoded similar to data where non-codebook-based precoding is applied.

Reference signals are considered to be one of the main causes of decreasing the energy efficiency of the 4G networks due to large amount of overhead in multi antenna transmission systems. Koorapaty *et al.* [62] proposes reduction of reference signal in frequency as well as time for energy efficient transmission.

In 5G networks, a variant of MIMO is proposed in which a very large number of antennas are employed at the base station called Massive MIMO. Using this technology, the base station 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 [63]. In [64], it is revealed that transmit power is decreased by the number of antennas at the base station so as to get same data rate like single antenna systems considering channel state information is known.

Besides power scaling law, the ways for improving energy efficiency in Massive MIMO systems have also received considerable attention. The energy efficiency decreases with increase in spectral efficiency with perfect channel state information has been shown in [65]. Whereas with imperfect channel state information, the energy efficiency increases with spectral efficiency in low power region and decreases in high power region. It is obvious that there are a large number of antennas in Massive MIMO which consume high circuit power hence causing considerable reduction in energy efficiency. In [66], technique of switching off some of the base station antennas is suggested similar to MIMO to improve the energy efficiency of the system. I *et al.* [67] suggests 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 Massive MIMO 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 massive MIMO and small cell access points installed in areas with active users with little additional hardware [68]. Many other techniques can also be used to improve energy efficiency which are a scope for future research.

E. RELAYS

Relays in a wireless system can be considered as an “agent” of base station outside its cell coverage area. These wireless relays allow the mobile terminals to help in forwarding of information when they are neither the source nor the destination of the information involved. The Gaussian relay channel was introduced in [69] and [70]. It extends high data rate coverage to the cell edge [71], [72]. Though, it was initially introduced to increase the coverage area of transmission only but later it was realized that relaying can be applied in a wireless communication system to not only increase the coverage area but also increase the throughput of the network, system capacity as well as decrease the transmission power [73].

The basic principle used in relaying is that in a relay assisted network, the mobile stations can receive signal from both base station (BS) as well as a Relay Node (RN) depending on which provides a better signal strength which mainly depends on the distance between them. This is what differentiates it from a normal wireless network in which each mobile station (MS) directly communicates with a base station [74]. Relaying splits longer paths into shorter ones by providing LOS communication and thus reducing the resulting total path loss. This consequently reduces the power required for transmission. This also reduces interference due to low transmission power.

Use of relays is a promising way to improve energy efficiency of a wireless network as already discussed. In [37], the advantages of using relays are discussed considering both transmission delay and power consumption. It has been

shown that using relays can reduce power consumption in CDMA cellular networks in [75]. The results show, the higher the path loss exponent, more is the saving in power. The tradeoff between energy and data rate using a relay in AWGN channel is shown in [76]. It also shows the impact of hop number, location of user and power allocated on Energy Efficiency.

The relay experiences fading conditions which are independent of the direct channel between source and the destination. Hence, this can be exploited for energy saving. In [77], it is shown that direct communication consumes less energy than using relays for shorter distances but after optimizing constellation size for different distances relays outperform direct communication.

Resource allocation is another challenge in relay networks for improving energy efficiency of the network. In [78], a sub-carrier pair based resource allocation for AF relays in OFDM system is used subject to power constraints for maximizing the throughput of the system. The problem of joint relay selection and power allocation is solved in [79] based on max-min user rate and total achievable rate. In [80], a dynamic subcarrier, bit and power allocation scheme involving relay selection and bandwidth exchange is proposed while maintaining users' QoS.

For selection of best relay node as well as optimal allocation of resources channel state information is indispensable. But acquiring it requires a lot of energy. So, there exists a tradeoff between overhead CSI and energy efficiency in a relay based networks. In [81], optimal power and rate allocation for an AF relay in AWGN channel assuming perfect global CSI is determined. But assuming perfect CSI is being too optimistic as imperfect CSI leads to degradation of performance in a wireless system [82]. In [106], the output signal-to-noise ratio is maximized under individual as well as aggregate relay power constraints for coherent and non-coherent amplify-and-forward (AF) relay networks considering imperfect CSI. The results reveal that ignoring uncertainties associated with global CSI often leads to poor performance.

Until now we considered one way relaying. But recently, techniques based on network coding with two way relaying have been used.

There exist three main relaying schemes: Decode-and-Forward, Compress-and-Forward and Amplify-and-Forward. The DF and AF schemes were first proposed in the pioneer article by Cover and El-Gamal in [83] and upper and lower bounds for a general relay channel were found.

- Decode-and-Forward (DF): In this relaying scheme as shown in figure 7, the relay decodes the source message in one block and transmits the re-encoded message in the following block instead of forwarding individual packets. This leads to fewer transmissions hence decreasing energy consumption [84].
- Amplify-and-Forward (AF): In this relaying scheme as shown in figure 8, the relay sends an amplified version of the received signal in the last time-slot.

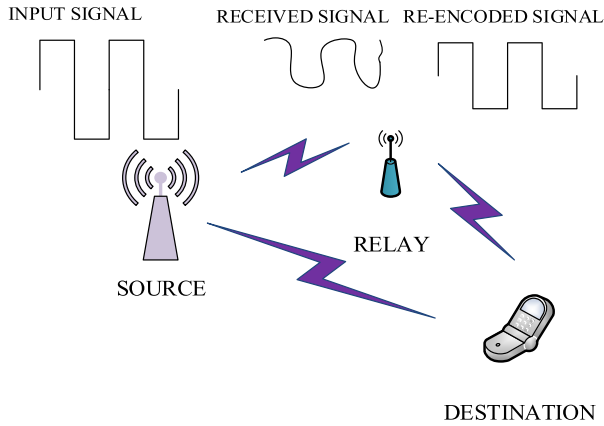


FIGURE 7. Decode and forward relay.

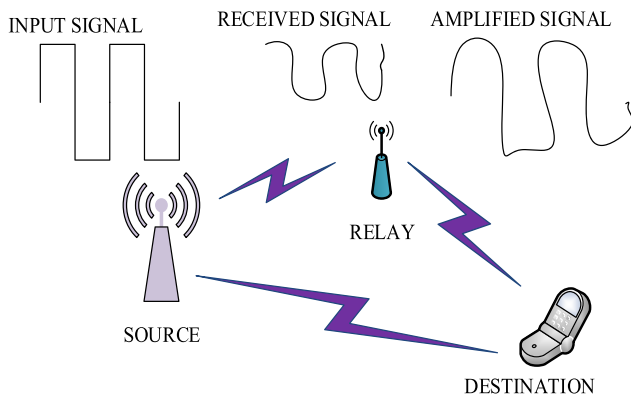


FIGURE 8. Amplify and forward relay.

- Compress-and-Forward (CF): In this relaying scheme, the relay quantizes the received signal in one block and transmits the encoded version of the quantized received signal in the following block.

Comparing with DF and CF, AF requires much less delay as the relay node operates time-slot by time-slot. Also, AF requires much less computing power as no decoding or quantizing operation is performed at the relay side. A network coding based scheme is proposed in [85] in OFDMA based relay networks called 'XOR-CD' which can be used to greatly improve energy efficiency.

Multiple relay systems require complex operations and consume more energy as well as resources. To overcome these disadvantages, a relay selection scheme is used which chooses a single best relay for transmission between relay and destination based on some criterion. Use of a single best relay using relay selection strategy and RTS/CTS mechanism and minimizing energy consumption per data packet can achieve higher energy efficiency as compared to use of multiple relays is shown in [86]. The results show that using power control schemes, single relay selection can outperform direct communication and prolongs the lifetime of the network. In [87] and [88] opportunistic Relay Selection (RS) scheme based on channel gains is proposed. After this several RS schemes were proposed with different selection criterion. In [89] and [90] relay node is selected based on least distance,

in [91] relay is selected based on highest transmission rate and in [92] and [93] based on signal to noise ratio. In [94], the effect of delay spread along with channel gain is also considered for RS. It minimizes the relay overhead by using variable Cyclic Prefix in an OFDM system with AF relay.

In the third generation partnership project's (3GPP) long term evolution-advanced (LTE-A) and IEEE 802.16j, relay standards have been detailed including in-band and out-band relaying as well as transparent and non-transparent connectivity of relay with users [95], [96]. But various issues like deployment of full duplex relays, D2D relaying, connectivity with mobile relays are left for implementation in next generation networks. The next generation networks are expected to support various different devices along with different applications. In [97], various relay selection policies are proposed for different types of applications. These are as follows:-

- A reduced channel estimation overhead policy is provided for high mobility scenarios.
- A delay minimization policy is given for delay critical applications.
- A low power consumption policy for power-efficient communications.

1) MATHEMATICAL MODEL

Let us consider a mathematical model consisting of a half-duplex relay with AWGN channel and let a denote the first time slot. The system model is shown in figure 9. The source which can either be the base station or a mobile node sends a signal $x_s[a]$. The received signals at the relay $y_r[a]$ and destination $y_d[a]$ are given as

$$y_r[a] = \sqrt{P_s}g_{s,r}x_s[a] + z_r[a] \quad (1)$$

$$y_d[a] = \sqrt{P_s}g_{s,d}x_s[a] + z_d[a] \quad (2)$$

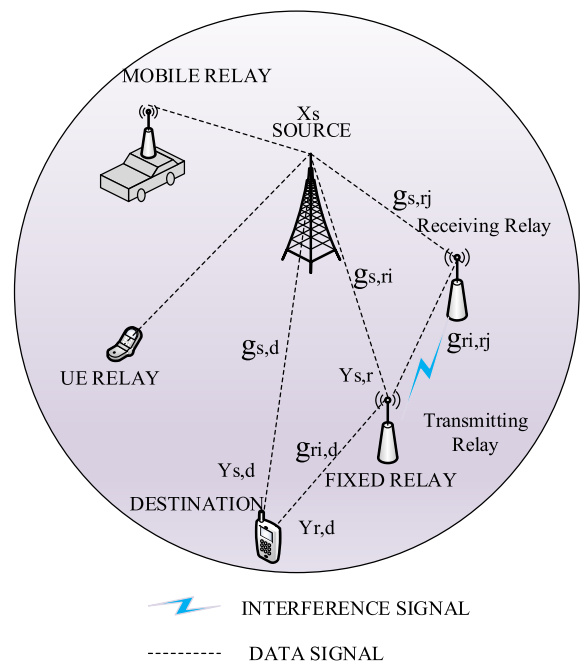


FIGURE 9. System mode.

In the second time slot ($a+1$), the source keeps silent and the relay transmits the signal $x_r[a+1]$ to the destination $y_d[a+1]$. In the above equations, $g_{i,j}$ is the channel coefficient between the transmitter and the receiver and z_j is the noise at the receiver with variance N_o , where $i \in \{s, r\}$ and $j \in \{r, d\}$. P_s represents the source transmission power.

For DF relay the retransmitted signals from the relay can be represented as

$$y_r[a+1] = \hat{x}_s[a] \quad (3)$$

For AF relay the transmitted signal is represented as

$$y_r[a+1] = \beta y_r[a] \quad (4)$$

Here β is the signal gain from the relay station and is given by

$$\beta = \frac{\sqrt{P_r}}{\sqrt{P_s |g_{s,r}|^2 + N_o}} \quad (5)$$

where P_r is the relay transmission power. The signal to noise ratio SNRs for source to relay, source to destination and relay to destination respectively are as follows:-

$$SNR_{s,r} = \frac{P_s |g_{s,r}|^2}{N_o} \quad (6)$$

$$SNR_{s,d} = \frac{P_s |g_{s,d}|^2}{N_o} \quad (7)$$

$$SNR_{r,d} = \frac{P_r |g_{r,d}|^2}{N_o} \quad (8)$$

The received signal at the destination from relay can be expressed as

$$y_{r,d} = \frac{\sqrt{P_r}}{\sqrt{P_s |g_{s,r}|^2 + N_o}} g_{r,d} y_r + z_{r,d} \quad (9)$$

Substituting equation (1) in above equation,

$$y_{r,d} = \frac{\sqrt{P_r}}{\sqrt{P_s |g_{s,r}|^2 + N_o}} \sqrt{P_s} g_{r,d} g_{s,r} x_s + z'_{r,d} \quad (10)$$

Here $z_{r,d}$ is the AWGN with variance N_o while $z'_{r,d}$ is the AWGN with variance N'_o given by

$$N'_o = \left(1 + \frac{P_r |g_{r,d}|^2}{P_s |g_{s,r}|^2 + N_o}\right) N_o \quad (11)$$

At the destination, there are two signals one received from the source and other from the relay. The final signal received is found using Maximal Ratio Combiner and is given as

$$y = h_1 y_{s,d} + h_2 y_{r,d} \quad (12)$$

where

$$h_1 = \frac{\sqrt{P_s} g_{s,d}}{N_o} \quad (13)$$

and

$$h_2 = \frac{\frac{\sqrt{P_r}}{\sqrt{P_s |g_{s,r}|^2 + N_o}} \sqrt{P_s} g_{s,r}^* g_{r,d}^*}{\left(1 + \frac{P_r |g_{r,d}|^2}{P_s |g_{s,r}|^2 + N_o}\right) N_o} \quad (14)$$

Now, let us consider an application as in [97] where reception is successful when the SNR at the receiver is above a SNR threshold σ_0 . So, instantaneous signal to noise ratio from source S to the relay selected for reception R_i for in-band and out-band relaying are respectively given by

$$\sigma_{SR_i} = \frac{g_{SR_i} P_s}{g_{R_j R_i} P_{R_j} + N_o} \geq \sigma_o \quad (15)$$

and

$$\sigma_{SR_i} = \frac{g_{SR_i} P_s}{N_o} \geq \sigma_o \quad (16)$$

Here g_{xy} represents the channel coefficient between the transmitter x and the receiver y and the noise at the receiver has the variance N_o . P_s represents the power of the source and P_{R_j} represents the power of the relay where R_j is the relay selected for transmission. For full-duplex mode $i = j$.

The instantaneous signal to noise ratio from relay selected for transmission R_j to the destination D considering no interference from source is given by

$$\sigma_{R_j D} = \frac{g_{R_j D} P_{R_j}}{N_o} \geq \sigma_o \quad (17)$$

From [98], the sum of powers in a particular time slot is considered for relay selection in case of successive relaying. Power is adjusted to fulfil the SNR threshold σ_o for a particular application. The power levels are defined as

$$P_{R_j} = \frac{\sigma_o N_o}{g_{R_j D}} \quad (18)$$

In case of reception with interference at relay, the source power from (15) is given by

$$P_s = \frac{\sigma_o (g_{R_j R_i} P_{R_j} + N_o)}{g_{SR_i}} \quad (19)$$

For full duplex transmission, single best relay selection is given by

$$R = \arg \min (P_s^* + P_{R_j}^*) \quad (20)$$

In case of reception without interference at relay, the power from source and max-link relay selection is respectively given by

$$P_s = \frac{\sigma_o N_o}{g_{SR_i}} \quad (21)$$

and

$$R = \arg \min \min \{P_s^*, P_{R_j}^*\} \quad (22)$$

This helps in choosing best possible relay for minimum power usage. A list of all the symbols used in the mathematical model is shown in table 3.

TABLE 3. Symbols and notations.

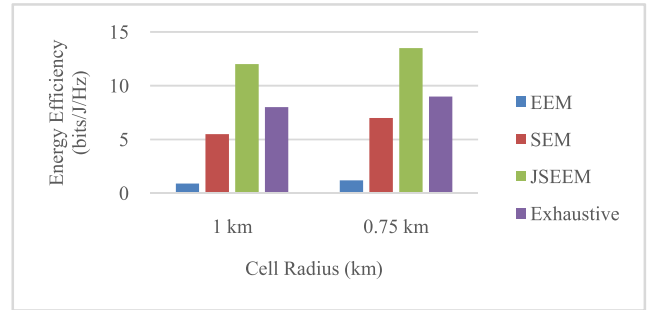
S.No.	Representation of Symbol	Meaning of Symbol
1	x_s	Source signal
2	y_r	Relay signal
3	y_d	Destination signal
4	$g_{i,j}$	Channel coefficient
5	z_j	Noise at receiver
6	N_o	Variance of noise
7	P_s	Source Power
8	P_r	Relay Power
9	β	Signal Gain of AF Relay
10	σ_0	SNR Threshold
11	σ_{ij}	SNR from source 'i' to destination 'j'

In present and future networks, relays are expected to act as both a source of information as well as a relay which is different from traditionally used pure relay systems. So, presently the focus is on exploiting channel state information, using relay selection schemes, relay enhanced architectures which includes deciding where and how may relay nodes to be placed and OFDMA based resource allocation in relay based network to save power and make the network energy efficient. Various algorithms have been used for improving EE of the network considering different parameters. In [80], EE is improved while maintaining QoS whereas in [99] output SNR is maximized and in [100] tradeoff between EE and fairness is considered. Both [103] and [104] use Dinkelbach's method for solving the problem of EE optimization. Zhou *et al.* [103] has lower complexity and achieves 99% optimal EE. In [101] to improve EE q-price is set based on interference level between nodes while in [102] it is based on fixed network price. Table 4 shows the summary of various algorithms that have been used for improving energy efficiency in relay based networks.

The value of energy efficiency in [103] and [104] has been compared in figure 10.

All the techniques we have discussed help in considerable energy saving.

From [107], using sleep modes efficiently in small cells and with the help of core network, EE of the system can be considerably improved. Zhang *et al.* [108] shows the energy efficiency improvement of AF relays in LTE deployment. Beamforming technique with the use of 4 antennas can cause great increase in power efficiency [109]. SWIPT improves energy consumption by 30% [110]. The power required by the use of C-RAN in a HetNet reduces by 70% [52]. The energy efficiency impact of each technique has been summarized in the table 5.

**FIGURE 10.** Comparison of algorithms.

VI. ENERGY EFFICIENT ARCHITECTURE

In present wireless network architecture, a centrally located base station is required by a mobile user to communicate whether present indoor or outdoor. When indoor users communicate using the outdoor base station 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 [111]. This idea will be supported with the help of massive MIMO technology [112] already discussed in previous section. Next generation architectures are expected to support various heterogeneous technologies and networks given in [113]. Each building is expected to have its own access point which will support indoor users and will communicate to the outdoor base station. 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 as already discussed 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, massive MIMO and cloud RAN for improving EE in the next generation network. The architecture proposed by us is shown in Figure 11.

The next generation networks are expected to have base station radius of about 500 meters and small cell radius of about 40 meters. We have considered four scenarios in our architecture. Firstly, the Base Station communicates directly with the MS which are in its coverage area and are located outdoors and hence suffer with lesser path loss due to good channel conditions. For Mobile Stations which suffer from higher path loss and hence require more power of the transmitting base station, we use relays. This brings us to our second scenario in which base station communicates with a mobile station through a relay hence consuming lesser power and making the network energy efficient. The transmitting power of a relay as well as base station can be minimized by optimum Relay Selection schemes and algorithms. 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 propose the next two scenarios for next generation networks to make them energy efficient. The indoor

TABLE 4. Algorithms for improving energy efficiency using relays.

Reference	Algorithm	Objective	Description	Inference
[105]	Relay Selection and Bandwidth Exchange Algorithm	To reduce energy consumption while maintaining quality of service in a network using OFDMA.	In this algorithm, firstly a heuristic energy saving relay selection scheme is implemented maintaining minimum QoS of user. Then resource allocation is done and the surplus subcarriers are reallocated using bandwidth exchange to save energy.	The proposed algorithm with bandwidth exchange is compared with algorithm without BE and a greedy algorithm. The results show that proposed algorithm with BE has maximum energy efficiency but minimum spectral efficiency out of three.
[106]	Relay Power Allocation Algorithm(RPA)	To maximize the output signal-to-noise ratio under individual as well as aggregate relay power constraints.	In this algorithm, coherent and non-coherent amplify-and-forward relay networks are analysed subject to power constraints for both perfect and imperfect channel state information.	The results reveal that ignoring uncertainties associated with global CSI often leads to poor performance highlighting the importance of robust algorithm designs in practical wireless networks.
[107]	1 Search for optimal power control method with trade-off between energy efficiency and fairness 2 Stochastic Power control	To develop optimal power control method with trade-off between energy efficiency and fairness	In this algorithm, the priority of each relay is set based on its power cost and channel conditions. Lower its value higher the priority. A relay node can only be selected when all nodes with higher priority are selected before. Then a scheme similar to LMS (least mean square algorithm) is applied for power control.	The results reveal that using convex optimization problem maximizes the lifetime of the network by using fairness criterion for each relay assuming that channel state information is already known.
[108]	Q Nash Algorithm	To use game theoretic approach to allocate powers among all the active nodes while maximizing network sum rate of relays and source EE.	In this algorithm, Q-values of different agents are calculated using reinforcement learning technique which depend on its experience gathered from environment. Then a feasibility check is performed based on QoS constraint of users. If unfeasible, BS takes over and performs admission control based on QoS requirement of nodes.	The results show that the full-duplex mode outperforms the half-duplex in terms of both energy efficiency and network sum-rate. The algorithm increases the EE of the system when either the number of relays increases or the number of sources decreases.
[108]	q-Price Algorithm	To obtain optimal power allocation for nodes.	In this algorithm, the interference power levels between nodes is compared to set their transmitting power until a convergence point is reached.	The results show that the optimal relay position in terms of the highest EE and SE comes close to the destination nodes as the number of antennas increases.
[109]	EEM (Energy Efficiency maximization) Algorithm to update q-Price	To obtain maximum energy efficiency while maintaining SE.	In this algorithm, the q-price algorithm is executed for a fixed network price until optimal convergence point is reached.	The results show that in a relay network a higher number of subcarriers decreases the SE but significantly increase the EE.
[110]	J-SEEM Algorithm	To jointly select active antennas of user and relay in order to maximize the energy efficiency of AF MIMO relay system.	This algorithm consists of two main parts: a fast selection scheme for the active antenna subsets at the relay and a user selection and transmission power optimization process based on required SNR using Dinkelbach's method.	The results show that algorithm has a probability of 99% to achieve the optimal EE with low complexity. It also achieves high gain even in low SNR regimes.
[111]	EEM (Energy Efficiency maximization)Algorithm	To improve the EE of a multi-relay, multi-user OFDMA system considering both power and subcarrier allocation.	In this algorithm, Dinkelbach's method is used to solve the optimization problem by solving a sequence of subtractive concave problems, which were solved using the dual decomposition approach.	The results show that when there is insufficient power for attaining maximum EE, algorithm reaches upper bound and doesn't make use of additional available power.
[112]	EE-MWM (Energy-efficient maximum weighted matching algorithm)	To improve the energy efficiency of the network by solving EE optimization problem.	In this algorithm, source users are matched to relay users to increase the capacity of source users and to improve the performance of cell-edge users in order to optimize the network.	The results show that the energy efficiency decreases when SNR threshold increases.
[113]	Network Energy Efficiency N-EE	To achieve optimized resource allocation scheme for network and relay energy consumption with a desirable data rate and vice versa using a Decode and Forward relay.	In this algorithm, total source and relay power consumption is minimized while maintaining a desired source rate.	The results show that minimizing the network energy consumption is not equivalent to maximizing the network capacity or rate. Four sub schemes have been used: two-hop relaying, full decode-forward, partial decode-forward with beamforming and without beamforming and each correspond to a different (source, relay or network) optimization problem.
[113]	Relay Energy Efficiency R-EE		In this algorithm, relay power consumption is minimized while keeping source power below a particular limit and maintaining a desired source rate.	
[113]	Source Energy Efficiency S-EE		In this algorithm, total source consumption is minimized while keeping relay power below a particular limit and maintaining a desired source rate. This is used in networks where relay power is not critical.	
[113]	Generalized Energy Efficiency G-EE		In this algorithm, the above three schemes are combined to achieve minimum energy consumption at given rate and power constraints.	

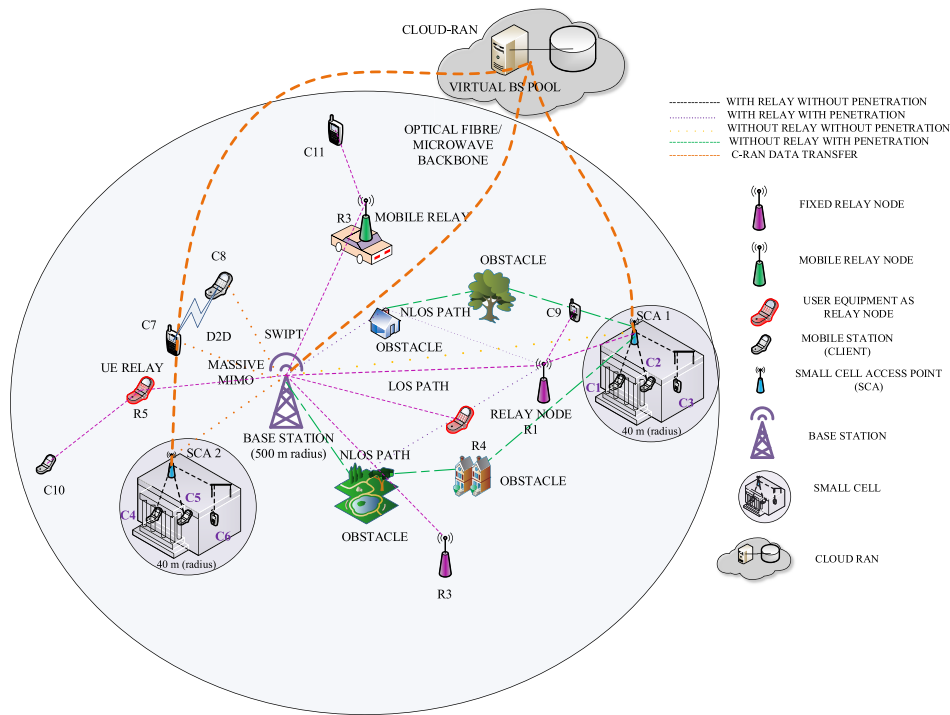


FIGURE 11. Proposed architecture for power optimization in 5G network.

TABLE 5. Energy saving by different techniques.

S.No.	Technique	Energy Efficiency
1	SWIPT	30%
2	Beamsteering (4 antennas)	55%
3	Small Cells	11.1%
4	C-RAN	21.2%
5	Massive MIMO (ZF processing)	30.7 Mbit/J
6	Massive MIMO (MMSE processing)	30.3 Mbit/J
7	Massive MIMO (MRT/MRC processing)	9.86 Mbit/J
8	AF Relays (LTE deployment)	9.7dB power reduction

users as discussed do not directly communicate with the base station. Instead they directly communicate with the small cell access point located in each building which in turn communicates with the base station. But there are certain situations when there is high path loss between the base station and the SCA as well. So to maintain the required quality of service and SNR along with satisfying the power constraints to make the network energy efficient, it is required to introduce a relay between base station and SCA. So, the last scenario we have considered is when the base station communicates with the relay which then sends the data to the specific Small Cell Access point of the building where Mobile Station is located indoors. These are the four scenarios which will be present in 5G network. To enhance the energy efficiency of the entire system, use of relays along with small cells is indispensable.

The base station in the next generation network is expected to support massive MIMO and SWIPT technology as shown in our architecture as well. All the communication will take place in the millimeter range wavelength.

C-RAN has also been integrated in our architecture being an eco-friendly infrastructure approach to improve the EE [114]. The backend connections to the virtual BS pool can either be provided by optical fiber or a microwave link. 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 which 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 turned off to save power during no load hour. Hence, C-RAN is expected to play a major role in energy saving.

To represent the various scenarios considered, we have taken different user equipment represented as clients in our architecture. C7, C8 and SCA2 directly communicate with the base station due to line of sight path and good channel conditions between them. C4, C5 and C6 are located indoors and hence send signal to SCA2 and not directly to the base station. SCA2 as located in line of sight path of base station doesn't require a relay. But C9, C10 and C11 along with SCA1 are not in line of sight path of the base station so require a relay for good reception as well as power optimization. The relay used can be mobile, fixed or UE relay. C1, C2 and C3 as shown communicate with SCA1 as they are located indoors. The SCA1 then communicates with the relay which in turn

communicates with the base station. The relay node is chosen according to relay selection policy for power optimization.

In our architecture, we have considered different channel conditions including both line of sight and non-line of sight paths as both have different path loss and hence will require different power from the base station to maintain the required SNR for a particular application. There can be four channel conditions which are without relay and without penetration that is simple line of sight path, without relay and with penetration that is due to various obstacles present in the channel. Thirdly, there is with relay without penetration and last is with relay with penetration which includes the path with relay as well as includes effect of reflection, refraction and diffraction through various obstacles present in the atmosphere. Also, in the indoor communication as well there are expected to be two paths, i.e., both line of sight and non-line of sight paths exist indoors as well. This is due to presence of obstacles inside the building as shown in our architecture. Now we discuss two cases in detail.

A. CASE 1: BS-SCA-C1

When a client located indoors wants to communicate with another client, instead of sending signal to the base station, it sends signals to the small cell access point in its vicinity. The SCA then sends the signal to the base station to establish the communication as shown in figure 12. This set up will be used in the next generation networks to reduce the path loss and hence the power consumption caused due to high penetration loss from the walls of the buildings. The base station now will not directly send signals to the indoor users but will make use of small cell access point.

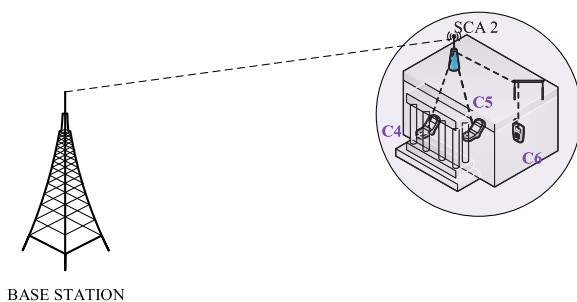


FIGURE 12. Transmission without relay.

B. CASE 2: BS-RN-SCA-C1

To further reduce the power consumption as well as improve the quality of the signal reaching the small cell access points not located in line of sight of base station, we make use of relays. As the relays are located in line of sight of the base station, it leads to lesser path loss and hence lower power consumption. The base station sends a low power signal to the relay selected for transmission which in turn sends the signal to the desired small cell access point in whose vicinity the client is located as shown in figure 13.

It should also be noted that in the next generation architecture, relays are expected to be of various types including

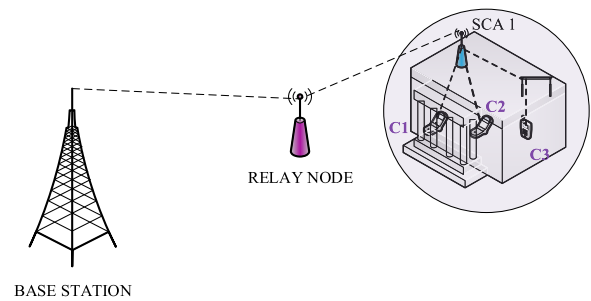


FIGURE 13. Transmission with relay.

both power supplied fixed relays as well as mobile battery dependent user equipment.

So, relay selection will have a major role in next generation networks to deliver the best possible quality of service as well as improve the energy efficiency of the network.

VII. GREEN COMMUNICATION

Telecommunication industry has experienced great success and demand in the recent past. The total number of mobile subscribers present are more than half of the global population. Presently, the ICT industry is becoming a major consumer of global energy. This has encouraged researchers to investigate various approaches for power consumption reduction. The motivation is twofold. Firstly, the telecommunication network operators are experiencing energy cost as a significant factor in profit calculations. Secondly, there exists a social responsibility of environmental protection by reducing carbon footprint due to information and communications technology.

Power consumption of a wireless network can be considered from two different perspectives: power consumed by base station and power consumed by mobile station. Although the average mobile phone is getting smaller, its functions are growing day by day and as a result energy consumption is also increase to support new applications. The various stages of the life cycle of a mobile device is shown in figure 14. It is the component manufacture and use phase of the lifecycle of a mobile phone which have the greatest environmental impact. The CO₂ emission from the lifecycle of a typical Ericson mobile was estimated to be 23.8 kg. The contribution of each stage of its lifecycle is shown in figure 15.

The power consumption by the base station forms a great part of the power consumption by the entire network. The use phase of its cycle is mainly responsible for increasing the carbon emissions. So, for improving the energy efficiency of the network and shifting towards green communication, a holistic approach needs to be adopted [115]. To reduce the power consumption by the mobile phone the approach of discontinuous reception can be used both in idle and connected mode [116] Mobile phone in DRX mode in idle state doesn't use any radio resources hence saving power. However, cDRX wakes up and shuts down the receiver circuit in a cyclic manner to save energy. A lot of innovation is

TABLE 6. Current projects in energy efficiency in wireless communication.

S.No.	Project Name	Aim of Research	Area of Research	HTTP Location
1	5GrEEen	To design environment friendly 5G Mobile networks.	Efficient mobile access networks and backhaul solutions	https://wireless.kth.se/5green/
2	OPERA-Net 2 (Optimizing Power Efficiency in Mobile Radio Networks 2)	To reduce the overall environmental impact of mobile radio networks by extending the results of OPERA-Net project.	Energy and material efficiency and use of renewable energy for telecom networks.	http://projects.celticplus.eu/opera-net2/
3	METIS II	To develop the 5G framework with efficient integration of various technologies.	5G radio access network design and developing an open-source 5G evaluation and visualization tool.	https://metis-ii.5g-ppp.eu/
4	ADEL (Advanced Dynamic Spectrum 5G mobile networks Employing Licensed shared access)	To develop future heterogeneous wireless networks of higher capacity and energy efficiency.	Licensed shared access (LSA), Decentralized spectrum sharing techniques, Advanced frequency agile transceiver techniques and Self-optimization techniques.	http://www.fp7-adel.eu/
5	5G PPP (5G Infrastructure Public Private Partnership)	To deliver solutions, architectures, technologies and standards for next generation networks.	Saving up to 90% of energy per service, ubiquitous super-fast connectivity and providing 1000 times higher capacity.	http://5g-ppp.eu/
6	COMBO (CONvergence of fixed and Mobile BrOadband access/aggregation networks)	To propose new approach for Fixed or Mobile Converged broadband access network for dense urban, urban and rural scenarios.	Joint optimization of fixed and mobile access networks and concept of Next Generation Point of Presence (NG-POP).	http://www.ict-combo.eu/index.php?id=about
7	DUPLO (Full-Duplex Radios for Local Access)	To develop new full-duplex radio transmission paradigm.	Focus on energy efficiency and technical solutions for efficient self-interference cancellation in wireless transceiver, access points and relay nodes.	http://www.fp7-duplo.eu/
8	iJOIN (Interworking and JOINT Design of an Open Access and Backhaul Network)	To improve the data rate of the next generation networks.	RAN-as-a-Service (RANaaS), radio access based upon small cells and a heterogeneous backhaul.	http://www.ict-ijoin.eu/
9	CROWD (Connectivity management for energy Optimized Wireless Dense network)	To shift towards global network cooperation and on demand capacity tuning.	Bringing density-proportional capacity, optimizing MAC mechanisms, enabling traffic-proportional energy consumption and designing smarter connectivity management solutions.	http://www.ict-crowd.eu/index.html
10	Wireless@MIT Center	To develop hardware and software designs for energy-efficient mobile systems.	Low-power handsets, energy-scavenging sensors, and wireless medical devices.	http://wireless.csail.mit.edu/Energy
11	Green Wireless Communication	To lower energy consumption of future wireless radio systems.	Development and performance analysis of new wireless channel estimation techniques, Transceiver design optimization under uncertainty and BS sleeping strategy.	https://sri-uq.kaust.edu.sa/Pages/greenwireless.aspx
12	Greenet	To analyze, design, and optimize energy efficient wireless communication systems and networks.	Cooperative communications, cognitive networks and network coding.	http://www.fp7-greenet.eu/default.php
13	GreenTouch	To deliver the architecture, specifications and roadmap to increase network energy efficiency by a factor of 1000	Energy efficient cloud, optical networks and home networks.	http://www.greentouch.org/

required both in terms of network planning and deployment as well as various green technologies need to be adopted to save the environment from the impact of CO₂ emissions.

There is another perspective to green communication which involves reducing the power emission levels both at transmitter as well as receiver end in order to protect humans

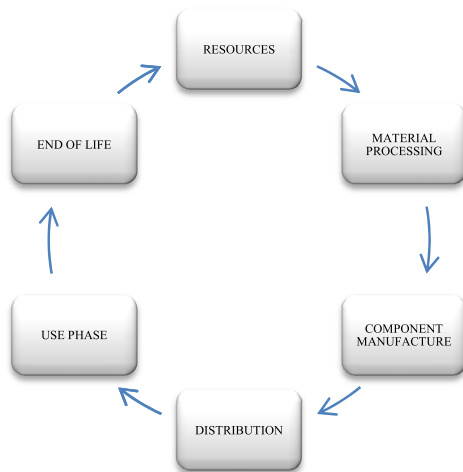


FIGURE 14. Life cycle assessment of mobile phone.

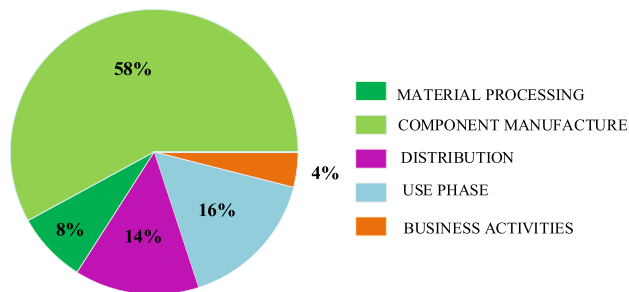


FIGURE 15. Carbon emissions in lifecycle of mobile phone.

from various health hazards. The governments have taken a step in this regard by enforcing safe exposure limit on the operators. The challenge on the part of the researchers is to maintain the desired QoS while adhering to the power limits for safe exposure.

VIII. FUTURE RESEARCH CHALLENGES

The next generation networks are expected to meet the needs of the consumers along with providing a solution for green communication. Use of new techniques such as SWIPT, massive MIMO, mm wave as well as continued use of small cells and relays in the next generation networks will impose new research challenges.

SWIPT is a promising technology for future but has unsatisfactory results for longer distances due to high path loss. Spatial diversity can be used to overcome this path loss. Thus, use of massive MIMO along with SWIPT need to be investigated for better results. Also, efficient circuit modules need to be developed which can reduce the power splitting loss as well as cost of the hardware.

Energy efficient resource management helps in saving huge amount of power. The handoff and coverage issues between neighboring small cells and its impact on EE needs to be further estimated. The QoS requirement of a particular application and time varying channel condition and its relation with EE needs to be developed.

TABLE 7. Relay classification.

LTE Relay Class	Format	Cell ID
Type 1	Inband Half Duplex	Present
Type 1.a	Outband Full Duplex	Present
Type 1.b	Inband Full Duplex	Present
Type 2	Inband Full Duplex	Absent

TABLE 8. Relay technologies.

Relay Technology	Advantages	Disadvantages
Layer 1 Relay	Simple, Inexpensive	Noise Amplified
Layer 2 Relay	Elimination of Noise	Processing Delay
Layer 3 Relay	Less impact on standard specification	Processing Delay

The next generation networks are expected to support heterogeneous networks. So, interference management as well as handoff between various networks with respect to EE needs to be studied. The tradeoff between spectral and energy efficiency for heterogeneous networks also needs further investigation. The selection of relays by combining various relay selection policies for a particular application and its impact on EE needs to be estimated. Also, the tradeoff between EE and acquiring CSI for relay selection needs to be further analyzed. The EE of massive MIMO network with full duplex relay channel needs to be studied. The EE of massive MIMO in multiple cell scenario needs to be investigated to eliminate the effect of interference. Further research also needs to be carried out for efficient implementation of base station sleep modes to save maximum possible power. The power allocation strategy by base station to small cells and its impact on the energy efficiency of the network needs investigation. The power control strategy and efficient algorithm in D2D communication to minimize interference at the same time ensuring optimum SNR needs to be developed. The impact of multiple antennas at base station and joint resource and power allocation is the possible future work in this regard. The trade-off between power consumed by hardware and power saving of the network by using massive MIMO with beamforming in the millimeter range also needs to be investigated along with the overall energy efficiency of the network.

IX. CONCLUSION

In this paper, we have discussed the growing need for energy efficiency in the next generation networks. We have analyzed the trends in the field of wireless communications in the last decade which indicated a shift towards pursuing green communication for the next generation network. The importance of choosing the appropriate EE metric has also been discussed. Further, we have gone through the various techniques which can be used in the future for optimizing the power of the network and the presented a summary of the work that has already been done to improve energy efficiency of network using these techniques. A system model for EE improvement with the use of relay selection 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

TABLE 9. List of abbreviations.

S.No.	Abbreviation	Meaning
1	EE	Energy Efficiency
2	MIMO	Multiple Input Multiple Output
3	SWIPT	Simultaneous Wireless Information and Power Transfer
4	ICT	Information and Communication Technology
5	3GPP	Third Generation Partnership Project
6	LTE-A	Long Term Evolution-Advanced
7	BS	Base Station
8	MS	Mobile Station
9	NMT	Nordic Mobile Telephone
10	TACS	Total Access Communication System
11	QoS	Quality of Service
12	SMS	Short Message Service
13	GSM	Global System for Mobile Communications
14	GPRS	General Packet Radio Service
15	EDGE	Enhanced Data Rate for GSM Evolution
16	CDMA	Code Division Multiple Access
17	IMT-2000	International Mobile Telecommunications 2000
18	ITU	International Telecommunication Union
19	UMTS	Universal Mobile Telecommunications System
20	DVB	Digital Video Broadcasting
21	BDMA	Beam Division Multiple Access
22	ICNIRP	International Commission on Non-Ionizing Radiation Protection
23	SSB	Single Side Band
24	BTS	Base Transceiver Station
25	OFDMA	Orthogonal Frequency Division Multiple Access
26	PAPR	Peak to Average Power Ratio
27	SC-FDMA	Single Carrier Frequency Division Multiple Access
28	SCA	Small Cell Access Point
29	D2D	Device to Device
30	DPS	Dynamic Power Save
31	SISO	Single Input Single Output
32	RAT	Radio Access Technology
33	WPT	Wireless Power Transfer
34	RF	Radio Frequency
35	DoF	Degree of Freedom
36	MU-MIMO	Multi User Multiple Input Multiple Output
37	RN	Relay Node
38	AWGN	Additive White Gaussian Noise

TABLE 9. (Continued.) List of abbreviations.

39	LOS	Line of Sight
40	AF	Amplify and Forward
41	CF	Compress and Forward
42	DF	Decode and Forward
43	CSI	Channel State Information
44	SNR	Signal to Noise Ratio
45	eNB	Evolved Node B
46	CRS	Cell-specific Reference Signal
47	MTC	Machine Type Communication
48	AAS	Active Antenna Systems
49	SON	Self-Organizing Network
50	CoMP	Coordinated Multi-Point Transmission and Reception
51	CA	Carrier Aggregation
52	DC	Dual Connectivity
53	RAN	Radio Access Network
54	DRX	Discontinuous Reception
55	cDRX	Connected state Discontinuous Reception
56	C-RAN	Cloud Radio Access Network
57	ZF	Zero Forcing
58	MMSE	Minimum Mean Square Error
59	MRT	Maximum Ratio Transmission
60	MRC	Maximum Ratio Combining
61	HetNet	Heterogeneous Network

using relays as will be present in the next generation along with small cells in millimeter range wavelength. EE techniques such as Massive MIMO, C-RAN and SWIPT have also been incorporated into it 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. The paper also provides the impact of life cycle analysis of a mobile on carbon footprint with the aim of pursuing green communication. Various challenges for future research for improving EE of wireless network have also been discussed.

APPENDIX

A. CURRENT RESEARCH PROJECTS

A list of current research projects being carried out for improving energy efficiency in next generation wireless networks is given in Table 6.

B. STANDARDIZATION ACTIVITY

Standardization work for the next-generation wireless networks is being carried out by the third generation partnership project's (3GPP) long term evolution-advanced (LTE-A)

and IEEE 802.16 standard for achieving high data rate and high capacity. The present release of LTE-A is Release 12 which includes several features like D2D, MTC, Dual connectivity and Small Cells.

LTE Relaying standards have always achieved attention. For a LTE relay, the UEs communicates with the relay node, which in turn communicates with a donor eNB. The various types of relays specified in release 10 of 3GPP standards in shown in table 7.

Based on the protocol architecture, Relays have been classified into L1, L2 and L3 relays. L1 are basically the amplify and forward relays while L2 are the decode and forward relays specified in Release 8 of 3GPP standard while the L3 relay was specified in Release 10 of 3GPP standard.

The advantages and disadvantages of each are shown in Table 8. The specifications for mobile relay nodes were standardized in Release 12 of 3GPP [117].

There are still many open issues in relays yet to be overcome. The next Release 13 is expected to come out in March, 2016 and is expected to support technologies like Active Antenna Systems, including beamforming, Multi-Input Multi-Output and Self-Organizing Network aspects, Coordinated Multi-Point Transmission and Reception, Carrier Aggregation enhancements and Dual Connectivity enhancements.

C. LIST OF ABBREVIATIONS

A list of abbreviations used in this paper have been shown in table 9.

REFERENCES

- [1] E. C. Strinati and L. Hérault, "Holistic approach for future energy efficient cellular networks," *Elektrotechnik Informationstechnik*, pp. 314–320, 2010.
- [2] *IMT Vision—Framework and Over-All Objectives of the Future Development of IMT for 2020 and Beyond*, document Rec. ITU-R M.2083-0, Sep. 2015.
- [3] L. M. Correia et al., "Challenges and enabling technologies for energy aware mobile radio networks," *IEEE Commun. Mag.*, vol. 48, no. 11, pp. 66–72, Nov. 2010.
- [4] C. Han et al., "Green radio: Radio techniques to enable energy-efficient wireless networks," *IEEE Commun. Mag.*, vol. 49, no. 6, pp. 46–54, Jun. 2011.
- [5] EARTH. *Energy Aware Radio and Network Technologies Project*. [Online]. Available: <https://www.ict-earth.eu/default.html>
- [6] Y. Yang, H. Hu, J. Xu, and G. Mao, "Relay technologies for WiMAX and LTE-advanced mobile systems," *IEEE Commun. Mag.*, vol. 47, no. 10, pp. 100–105, Oct. 2009.
- [7] K. R. Santhi, "Goals of true broad band's wireless next wave (4G-5G)," in *Proc. IEEE 58th Veh. Technol. Conf. (VTC-Fall)*, vol. 4, Oct. 2003, pp. 2317–2321.
- [8] A. Goldsmith, *Wireless Communications*. Cambridge, U.K.: Cambridge Univ. Press, 2009.
- [9] T. S. Rappaport, *Wireless Communications: Principles and Practice*, vol. 2. Englewood Cliffs, NJ, USA: Prentice-Hall, 1996.
- [10] S. W. Peters, A. Y. Panah, K. T. Truong, and R. W. Heath, "Relay architectures for 3GPP LTE-Advanced," *EURASIP J. Wireless Commun. Netw.*, vol. 2009, p. 618787, Jul. 2009.
- [11] *A Case Study on Arbitrary Radio Frequency Exposure Limits: Impact on 4G Network Deployment*, GSMA, Brussels, Italy, 2014, pp. 1–24.
- [12] Y. Chen et al., "Fundamental trade-offs on green wireless networks," *IEEE Commun. Mag.*, vol. 49, no. 6, pp. 30–37, Jun. 2011.
- [13] *Most Promising Tracks of Green Network Technologies*, INFOS-ICT-247733 EARTH Deliverable D3.1, Earth, WP3-Green Networks, 2010. [Online]. Available: https://bscw.ict-earth.eu/pub/bscw.cgi/d31509/EARTH_WP3_D3.1.pdf
- [14] Wireless@KTH. *EWIN: Energy-Efficient Wireless Networking*. [Online]. Available: <http://www.wireless.kth.se/research/projects/19-ewin>
- [15] *Energy Efficiency Enhancements in Radio Access Networks*, Wireless@KTH Research Strategy Document 2008-2010, Wireless@KTH, 2008. [Online]. Available: http://www.wireless.kth.se/images/stories/Strategy/Research_plan08.pdf
- [16] OPERA-Net. *Optimising Power Efficiency in Mobile Radio Networks Project*. [Online]. Available: <http://opera-net.org/default.aspx>
- [17] *NEM Summit 2008—Towards Future Media Internet*, document OPERA-Net PROJECT STAND #42, Barcelona, Spain, Oct. 2010.
- [18] P. Grant, "MCVE core 5 programme, green radio—The case for more efficient cellular basestations," presented at the GLOBECOM, 2010.
- [19] G. Auer et al., "Enablers for energy efficient wireless networks," in *Proc. IEEE 72nd IEEE Veh. Technol. Conf. Fall (VTC-Fall)*, Sep. 2010, pp. 1–5.
- [20] M. A. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal energy savings in cellular access networks," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC)*, Jun. 2009, pp. 1–5.
- [21] H. Zhang, *Cognitive Radio for Green Communications and Green Spectrum*, CHINACOM, Hangzhou, China, Aug. 2008.
- [22] Y. Chen, S. Zhang, and S. Xu, "Characterizing energy efficiency and deployment efficiency relations for green architecture design," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC)*, May 2010, pp. 1–5.
- [23] B. Badic, T. O'Farrell, P. Loskot, and J. He, "Energy efficient radio access architectures for green radio: Large versus small cell size deployment," in *Proc. IEEE 70th IEEE Veh. Technol. Conf. Fall (VTC-Fall)*, Sep. 2009, pp. 1–5.
- [24] H. Claussen, L. T. W. Ho, and F. Pivert, "Effects of joint macrocell and residential picocell deployment on the network energy efficiency," in *Proc. IEEE 19th Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC)*, Sep. 2008, pp. 1–6.
- [25] F. Cao and Z. Fan, "The tradeoff between energy efficiency and system performance of femtocell deployment," in *Proc. 7th Int. Symp. IEEE Wireless Commun. Syst. (ISWCS)*, Sep. 2010, pp. 315–319.
- [26] Y. Hou and D. Laurenson, "Energy efficiency of high QoS heterogeneous wireless communication network," in *Proc. IEEE 72nd Veh. Technol. Conf. Fall (VTC-Fall)*, Sep. 2010, pp. 1–5.
- [27] M. Jada, M. M. A. Hossain, J. Hämäläinen, and R. Jäntti, "Impact of femtocells to the WCDMA network energy efficiency," in *Proc. 3rd IEEE Int. Conf. Broadband Netw. Multimedia Technol. (IC-BNMT)*, Oct. 2010, pp. 305–310.
- [28] D. Ezri and S. Shilo, "Green cellular—Optimizing the cellular network for minimal emission from mobile stations," in *Proc. IEEE Int. Conf. Microw., Commun., Antennas Electron. Syst. (COMCAS)*, Nov. 2009, pp. 1–5.
- [29] L. Lin, N. B. Shroff, and R. Srikant, "Asymptotically optimal energy-aware routing for multihop wireless networks with renewable energy sources," *IEEE/ACM Trans. Netw.*, vol. 5, no. 5, pp. 1021–1034, Oct. 2007.
- [30] Alcatel-Lucent, "Alcatel-lucent demonstrates up to 27 percent power consumption reduction on base stations deployed by China mobile: Software upgrades can offer exceptional power and cost savings for mobile operators worldwide," presented at the Mobile World Congr., Barcelona, Spain, Feb. 2009.
- [31] J. Gong, S. Zhou, Z. Niu, and P. Yang, "Traffic-aware base station sleeping in dense cellular networks," in *Proc. 18th Int. Workshop Quality Service (IWQoS)*, Jun. 2010, pp. 1–2.
- [32] L. Chiaraviglio, D. Ciullo, M. Meo, and M. A. Marsan, "Energy-efficient management of UMTS access networks," in *Proc. 21st Int. Teletraffic Congr. (ITC)*, 2009, pp. 1–8.
- [33] F. Han, Z. Safar, W. S. Lin, Y. Chen, and K. J. R. Liu, "Energy-efficient cellular network operation via base station cooperation," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Ottawa, ON, Canada, Jun. 2012, pp. 4374–4378.
- [34] S. Cui, A. J. Goldsmith, and A. Bahai, "Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks," *IEEE J. Sel. Areas Commun.*, vol. 22, no. 6, pp. 1089–1098, Aug. 2004.
- [35] H. Kim, C. B. Chae, G. de Veciana, and R. W. Heath, "A cross-layer approach to energy efficiency for adaptive MIMO systems exploiting spare capacity," *IEEE Trans. Wireless Commun.*, vol. 8, no. 8, pp. 4264–4275, Aug. 2009.
- [36] B. Bougard, G. Lenoir, A. Dejonghe, L. Van der Perre, F. Catthoor, and W. Dehaene, "SmartMIMO: An energy-aware adaptive MIMO-OFDM radio link control for next-generation wireless local area networks," *EURASIP J. Wireless Commun. Netw.*, vol. 2007, no. 3, p. 13, 2007.

- [37] G. Miao, N. Himayat, Y. Li, and A. Swami, "Cross-layer optimization for energy-efficient wireless communications: A survey," *Wireless Commun. Mobile Comput.*, vol. 9, no. 4, pp. 529–542, 2009.
- [38] A. J. Goldsmith and S. B. Wicker, "Design challenges for energy-constrained ad hoc wireless networks," *IEEE Wireless Commun. Mag.*, vol. 9, no. 4, pp. 8–27, Aug. 2002.
- [39] D. Feng, C. Jiang, G. Lim, L. J. Cimini, Jr., G. Feng, and G. Y. Li, "A Survey of Energy-Efficient Wireless Communications," *IEEE Commun. Surveys Tuts.*, vol. 15, no. 1, pp. 167–178, Nov. 2013.
- [40] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, "Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective," *IEEE Wireless Commun.*, vol. 21, no. 3, pp. 118–127, Jun. 2014.
- [41] G. Wu, C. Yang, S. Li, and G. Y. Li, "Recent advances in energy-efficient networks and their application in 5G systems," *IEEE Wireless Commun.*, vol. 22, no. 2, pp. 145–151, Apr. 2015.
- [42] H. Kwon and T. G. Birdsall, "Channel capacity in bits per joule," *IEEE J. Ocean. Eng.*, vol. 11, no. 1, pp. 97–99, Jan. 1986.
- [43] R. G. Gallager, "Energy limited channels: Coding, multiaccess, and spread spectrum," in *Proc. Conf. Inf. Sci. Syst.*, Mar. 1988, p. 372.
- [44] S. Verdú, "On channel capacity per unit cost," *IEEE Trans. Inf. Theory*, vol. 36, no. 5, pp. 1019–1030, Sep. 1990.
- [45] S. Verdú, "Spectral efficiency in the wideband regime," *IEEE Trans. Inf. Theory*, vol. 48, no. 6, pp. 1319–1343, Jun. 2002.
- [46] O. Arnold, F. Richter, G. Fettweis, and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks," in *Proc. Future Netw. Mobile Summit*, 2010, pp. 1–8.
- [47] S. Cui, A. J. Goldsmith, and A. Bahai, "Energy-constrained modulation optimization," *IEEE Trans. Wireless Commun.*, vol. 4, no. 5, pp. 2349–2360, Sep. 2005.
- [48] K. Huang and E. Larsson, "Simultaneous information and power transfer for broadband wireless systems," *IEEE Trans. Signal Process.*, vol. 61, no. 23, pp. 5972–5986, Dec. 2013.
- [49] I. Krikidis, S. Timotheou, S. Nikolaou, G. Zheng, D. M. K. Ng, and R. Schober, "Simultaneous wireless information and power transfer in modern communication systems," *IEEE Commun. Mag.*, vol. 52, no. 11, pp. 104–110, Nov. 2014.
- [50] Y. Niu, "A survey of millimeter wave communications (mmWave) for 5G: Opportunities and challenges," *Wireless Netw.*, vol. 21, no. 8, pp. 2657–2676, 2015.
- [51] T. S. Rappaport *et al.*, "Millimeter wave mobile communications for 5G cellular: It will work!" *IEEE Access*, vol. 1, no. 1, pp. 335–349, Aug. 2013.
- [52] L. Chen, H. Jin, H. Li, J. B. Seo, Q. Guo, and V. Leung, "An energy efficient implementation of C-RAN in HetNet," in *Proc. IEEE 80th Veh. Technol. Conf. (VTC Fall)*, Vancouver, BC, Canada, Sep. 2014, pp. 1–5.
- [53] A. Prasad, O. Tirkkonen, P. Lunden, O. N. C. Yilmaz, L. Dalsgaard, and C. Wijting, "Energy-efficient inter-frequency small cell discovery techniques for LTE-advanced heterogeneous network deployments," *IEEE Commun. Mag.*, vol. 51, no. 5, pp. 72–81, May 2013.
- [54] Z. Niu, S. Zhou, S. Zhou, X. Zhong, and J. Wang, "Energy efficiency and resource optimized hyper-cellular mobile communication system architecture and its technical challenges," *Sci. Sin.*, vol. 42, no. 10, pp. 1191–1203, 2012.
- [55] X. Xu, G. He, S. Zhang, Y. Chen, and S. Xu, "On functionality separation for green mobile networks: Concept study over LTE," *IEEE Commun. Mag.*, vol. 51, no. 5, pp. 82–90, May 2013.
- [56] W. Liu, X. Li, and M. Chen, "Energy efficiency of MIMO transmissions in wireless sensor networks with diversity and multiplexing gains," in *Proc. IEEE Int. Acoust., Speech, Signal Process.*, Mar. 2005, pp. 897–900.
- [57] S. K. Jayaweera, "Virtual MIMO-based cooperative communication for energy-constrained wireless sensor networks," *IEEE Trans. Wireless Commun.*, vol. 5, no. 5, pp. 984–989, May 2006.
- [58] S. Hussain, A. Azim, and J. H. Park, "Energy efficient virtual MIMO communication for wireless sensor networks," *Telecommun. Syst.*, vol. 42, nos. 1–2, pp. 139–149, 2009.
- [59] L. Wan, "An energy efficient DOA estimation algorithm for uncorrelated and coherent signals in virtual MIMO systems," *Telecommun. Syst.*, vol. 59, no. 1, pp. 93–110, 2015.
- [60] T.-T. Tran, Y. Shin, and O.-S. Shin, "Overview of enabling technologies for 3GPP LTE-advanced," *EURASIP J. Wireless Commun. Netw.*, vol. 2012, p. 54, Feb. 2012.
- [61] I. F. Akyildiz, D. M. Gutierrez-Estevéz, and E. C. Reyes, "The evolution to 4G cellular systems: LTE-Advanced," *Phys. Commun.*, vol. 3, no. 4, pp. 217–244, 2010.
- [62] H. Koorapaty, J. F. Cheng, J. C. Guey, and S. Grant, "Reference signals for improved energy efficiency in LTE," in *Proc. IEEE 78th Veh. Technol. Conf. (VTC Fall)*, Sep. 2013, pp. 1–5.
- [63] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 186–195, Feb. 2014.
- [64] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Trans. Commun.*, vol. 61, no. 4, pp. 1436–1449, Apr. 2013.
- [65] J. Nam, J.-Y. Ahn, A. Adhikary, and G. Caire, "Joint spatial division and multiplexing: Realizing massive MIMO gains with limited channel state information," in *Proc. 46th Annu. Conf. Inf. Sci. Syst. (CISS)*, Mar. 2012, pp. 1–6.
- [66] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Trans. Commun.*, vol. 61, no. 4, pp. 1436–1449, Apr. 2013.
- [67] C.-L. I, C. Rowell, S. Han, Z. Xu, G. Li, and Z. Pan, "Toward green and soft: A 5G perspective," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 66–73, Feb. 2014.
- [68] E. Björnson, M. Kountouris, and M. Debbah, "Massive MIMO and small cells: Improving energy efficiency by optimal soft-cell coordination," in *Proc. 20th Int. Conf. Telecommun. (ICT)*, Casablanca, Morocco, 2013, pp. 1–5.
- [69] E. C. van der Meulen, "Three-terminal communication channels," *Adv. Appl. Probab.*, vol. 3, no. 1, pp. 120–154, 1971.
- [70] E. van der Meulen, "A survey of multi-way channels in information theory: 1961–1976," *IEEE Trans. Inf. Theory*, vol. 23, no. 1, pp. 1–37, Jan. 1977.
- [71] R. Pabst *et al.*, "Relay-based deployment concepts for wireless and mobile broadband radio," *IEEE Wireless Commun. Mag.*, vol. 42, no. 9, pp. 80–89, Sep. 2004.
- [72] M. Salem, A. Adinoyi, H. Yanikomeroglu, and D. Falconer, "Opportunities and challenges in OFDMA-based cellular relay networks: A radio resource management perspective," *IEEE Trans. Veh. Technol.*, vol. 59, no. 5, pp. 2496–2510, Jun. 2010.
- [73] M. H. Islam, Z. Dziong, K. Sohraby, M. F. Daneshmand, and R. Jana, "Joint optimal power allocation and base station and relay station placement in wireless relay networks," in *Proc. Int. Conf. Inf. Netw.*, 2012, pp. 1–6.
- [74] R. K. Jha, V. Mishra, K. Yadav, and S. Manhas, "Power optimization of wireless network," in *Proc. Annu. IEEE India Conf. (INDICON)*, Dec. 2013, pp. 1–6.
- [75] A. Radwan and H. S. Hassanein, "NXG04-3: Does multi-hop communication extend the battery life of mobile terminals?" in *Proc. IEEE Global Telecommun. Conf. (GLOBECOM)*, San Francisco, CA, USA, 2006, pp. 1–5.
- [76] C. Bae and W. E. Stark, "End-to-end energy-bandwidth tradeoff in multihop wireless networks," *IEEE Trans. Inf. Theory*, vol. 55, no. 9, pp. 4051–4066, Sep. 2009.
- [77] Q. Chen and M. C. Gursoy, "Energy-efficient modulation design for reliable communication in wireless networks," in *Proc. 43rd Annu. Conf. Inf. Sci. Syst. (CISS)*, Mar. 2009, pp. 811–816.
- [78] W. Dang, M. Tao, H. Mu, and J. Huang, "Subcarrier-pair based resource allocation for cooperative multi-relay OFDM systems," *IEEE Trans. Wireless Commun.*, vol. 9, no. 5, pp. 1640–1649, May 2010.
- [79] S. Kaddoor and R. Adve, "Relay selection and power allocation in cooperative cellular networks," *IEEE Trans. Wireless Commun.*, vol. 9, no. 5, pp. 1676–1685, May 2010.
- [80] H. Bo, F. Xuming, Z. Yue, C. Yu, and H. Rong, "Dynamic energy saving subcarrier, bit and power allocation in OFDMA relay networks," *China Commun.*, vol. 10, no. 4, pp. 79–87, Apr. 2013.
- [81] I. Maric and R. D. Yates, "Bandwidth and power allocation for cooperative strategies in Gaussian relay networks," *IEEE Trans. Inf. Theory*, vol. 56, no. 4, pp. 1880–1889, Apr. 2010.
- [82] W. M. Gifford, M. Z. Win, and M. Chiani, "Diversity with practical channel estimation," *IEEE Trans. Wireless Commun.*, vol. 4, no. 4, pp. 1935–1947, Jul. 2005.
- [83] T. M. Cover and A. A. El Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inf. Theory*, vol. 25, no. 5, pp. 572–584, Sep. 1979.
- [84] V. Tarokh, Ed., *New Directions in Wireless Communications Research*. Springer Verlag, 2009.
- [85] H. Xu and B. Li, "XOR-assisted cooperative diversity in OFDMA wireless networks: Optimization framework and approximation algorithms," in *Proc. IEEE INFOCOM*, Apr. 2009, pp. 2141–2149.

- [86] Z. Zhou, S. Zhou, J. H. Cui, and S. Cui, "Energy-efficient cooperative communication based on power control and selective single-relay in wireless sensor networks," *IEEE Trans. Wireless Commun.*, vol. 7, no. 8, pp. 3066–3078, Aug. 2008.
- [87] A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 3, pp. 659–672, Mar. 2006.
- [88] A. Bletsas, H. Shin, and M. Z. Win, "Cooperative communications with outage-optimal opportunistic relaying," *IEEE Trans. Wireless Commun.*, vol. 6, no. 9, pp. 3450–3460, Sep. 2007.
- [89] Y. Zou, J. Zhu, B. Zheng, and Y.-D. Yao, "An adaptive cooperation diversity scheme with best-relay selection in cognitive radio networks," *IEEE Trans. Signal Process.*, vol. 58, no. 10, pp. 5438–5445, Oct. 2010.
- [90] V. Sreng, H. Yanikomeroglu, and D. D. Falconer, "Relayer selection strategies in cellular networks with peer-to-peer relaying," in *Proc. IEEE 58th Veh. Technol. Conf. (VTC-Fall)*, vol. 3, Oct. 2003, pp. 1949–1953.
- [91] E. Altubaiishi and S. Shen, "Variable-rate based relay selection scheme for decode-and-forward cooperative networks," in *Proc. IEEE Wireless Commun. Netw. Conf.*, Mar. 2011, pp. 1887–1891.
- [92] Y. Jing and H. Jafarkhani, "Single and multiple relay selection schemes and their achievable diversity order," *IEEE Trans. Wireless Commun.*, vol. 8, no. 3, pp. 1414–1423, Mar. 2009.
- [93] Y. Zhao, R. Adve, and T. J. Lim, "Improving amplify-and-forward relay networks: Optimal power allocation versus selection," *IEEE Trans. Wireless Commun.*, vol. 6, no. 8, pp. 3114–3123, Aug. 2007.
- [94] X. Gao, X. Wang, and Y. Zou, "Relay selection scheme with adaptive cyclic prefix for cooperative amplify-and-forward relay," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2013, pp. 1939–1943.
- [95] *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further Advancements for E-UTRA Physical Layer Aspects*, document 3GPP TR 36.814 v.9.0.0, Mar. 2010.
- [96] *IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Broadband Wireless Access Systems Amendment 1: Multi-hop Relay Specification*, IEEE Standard 802.16j, Jun. 2009.
- [97] N. Nomikos, D. N. Skoutas, and P. Makris, "Relay selection in 5G networks," in *Proc. Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, Aug. 2014, pp. 821–826.
- [98] N. Nomikos, T. Charalambous, I. Krikidis, D. N. Skoutas, D. Vouyioukas, and M. Johansson, "Buffer-aided successive opportunistic relaying with inter-relay interference cancellation," in *Proc. IEEE 24th Pers. Indoor. Mobile Radio Commun. (PIMRC)*, London, U.K., Sep. 2013, pp. 1321–1325.
- [99] T. Q. S. Quek, M. Z. Win, and M. Chiani, "Robust power allocation algorithms for wireless relay networks," *IEEE Trans. Commun.*, vol. 58, no. 7, pp. 1931–1938, Jul. 2010.
- [100] D. Wang, X. Wang, and X. Cai, "Optimal power control for multi-user relay networks over fading channels," *IEEE Trans. Wireless Commun.*, vol. 10, no. 1, pp. 199–207, Jan. 2011.
- [101] F. Shams, G. Bacci, and M. Luise, "Energy-efficient power control for multiple-relay cooperative networks using Q -learning," *IEEE Trans. Wireless Commun.*, vol. 14, no. 3, pp. 1567–1580, Mar. 2015.
- [102] K. Singh and M. L. Ku, "Toward green power allocation in relay-assisted multiuser networks: A pricing-based approach," *IEEE Trans. Wireless Commun.*, vol. 14, no. 5, pp. 2470–2486, May 2015.
- [103] X. Zhou, B. Bai, and W. Chen, "A low complexity energy efficiency maximization method for multiuser amplify-and-forward MIMO relay systems with a holistic power model," *IEEE Commun. Lett.*, vol. 18, no. 8, pp. 1371–1374, Aug. 2014.
- [104] K. T. K. Cheung, S. Yang, and L. Hanzo, "Achieving maximum energy-efficiency in multi-relay OFDMA cellular networks: A fractional programming approach," *IEEE Trans. Wireless Commun.*, vol. 61, no. 7, pp. 2746–2757, Jul. 2013.
- [105] Y. Li, "Energy-efficient optimal relay selection in cooperative cellular networks based on double auction," *IEEE Trans. Wireless Commun.*, vol. 14, no. 8, pp. 4093–4104, Aug. 2015.
- [106] F. Parzysz, M. Vu, and F. Gagnon, "Energy minimization for the half-duplex relay channel with decode-forward relaying," *IEEE Trans. Commun.*, vol. 61, no. 6, pp. 2232–2247, Jun. 2013.
- [107] I. Ashraf, F. Boccardi, and L. Ho, "SLEEP mode techniques for small cell deployments," *IEEE Commun. Mag.*, vol. 49, no. 8, pp. 72–79, Aug. 2011.
- [108] J. Zhang, L. L. Yang, and L. Hanzo, "Power-efficient opportunistic amplify-and-forward single-relay aided multi-user SC-FDMA uplink," in *Proc. IEEE 71st Veh. Technol. Conf. (VTC-Spring)*, May 2010, pp. 1–5.
- [109] H. Yu, L. Zhong, and A. Sabharwal, "Beamsteering on mobile devices: Network capacity and client efficiency," Dept. Elect. Comput. Eng., Rice Univ., Houston, TX, USA, Tech. Rep. 06-23-2010, Jun. 2010.
- [110] Z. Chang, J. Gong, T. Ristaniemi, and Z. Niu, "Energy efficient resource allocation and user scheduling for collaborative mobile clouds with hybrid receivers," *IEEE Trans. Veh. Technol.*, vol. PP, no. 99, p. 1, 2016.
- [111] C.-X. Wang *et al.*, "Cellular architecture and key technologies for 5G wireless communication networks," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 122–130, Feb. 2014.
- [112] M. Olsson, C. Cavdar, P. Frenger, S. Tombaz, D. Sabella, and R. Jantti, "5GrEEn: Towards green 5G mobile networks," in *Proc. IEEE 9th Int. Conf. Wireless Mobile Comput., Netw. Commun. (WiMob)*, Oct. 2013, pp. 212–216.
- [113] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE Access*, vol. 3, no. 7, pp. 1206–1232, Aug. 2015.
- [114] China Mobile Research Institute, "C-RAN road towards green radio access network," China Mobile, Beijing, China, White Paper, Version 2.5, Oct. 2011, pp. 1–48.
- [115] L. Collins, "Greening the global network," *Eng. Technol.*, vol. 5, no. 4, pp. 64–65, Mar. 2010.
- [116] C. Zhong, T. Yang, L. Zhang, and J. Wang, "A new discontinuous reception (DRX) scheme for LTE-advanced carrier aggregation systems with multiple services," in *Proc. IEEE Veh. Technol. Conf. (VTC Fall)*, San Francisco, CA, USA, Sep. 2011, pp. 1–5.
- [117] *Further Advancements for E-UTRA Physical Layer Aspects (Release 12)*, document 3GPP TS 36.942, Sep. 2014.



AKSHITA ABROL (S'16) received the B.E. degree in electronics and communication engineering from Jammu University, Jammu and Kashmir, India, in 2013. She is currently pursuing the M.Tech. degree in electronics and communication engineering with Shri Mata Vaishno Devi University, Jammu and Kashmir.



RAKESH KUMAR JHA (S'10–M'13–SM'15) received the B.Tech. degree in electronics and communication engineering in Bhopal, India, the M.Tech. degree from NIT Jalandhar, India, and the Ph.D. degree from NIT Surat, India, in 2013. He is currently an Assistant Professor with the Department of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Jammu and Kashmir, India. He is carrying out his research on wireless communication, power

optimizations, wireless security issues, and optical communications.

He has authored over 30 international journal papers and more than 20 international conference papers. His area of interest is wireless communication, optical fiber communication, computer networks, and security issues.

Dr. Jha's concept related to router of wireless communication has been accepted by the International Telecommunication Union in 2010. He received the Young Scientist Author Award from ITU in 2010, the APAN Fellowship in 2011 and 2012, and the Student Travel Grant from COMSNET in 2012. He is a Senior Member of the Global ICT Standardization Forum for India, the Society for Industrial and Applied Mathematics, the International Association of Engineers, and the Advance Computing and Communication Society.

• • •