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A compendium of optimization techniques for green radio resource management

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Abstract In recent past, along with other sectors, the telecommunication sector has grown enormously that have significant effects both on power expenditure and environmental hazards. Therefore, this paper presents the comprehensive overview about the energy efficiency and green communication. This paper summarizes the efforts that have been made in attaining green wireless communication in the perspective of radio resource management. The key interest in carrying this survey is to indicate those areas for the research that can be flourished more while attaining our goal of green wireless communication. In this article, basic concepts of energy-efficient communications are first introduced and then existing fundamental works and advanced techniques for energy efficiency are summarized, including information-theoretic analysis, OFDMA networks, MIMO techniques, relay transmission, and wireless resource allocation. Some of the important areas in energy-efficient design are also identified for future research.

Keywords Energy efficiency · Green communication · Resource management · Multi-objective

1 Introduction

Energy resources can be considered as one of the major strength for any country or individual ever since from the existence of this world. Nonetheless, this notion has increased immensely in today's technological world with hardly any individual who has no dependency on it. The recent enormous growth in telecommunication industry specially the mobile industry has aggravated this proposition further by resulting in increased energy budget. This criss-cross between energy and drastic communication usage has largely invoked a slogan of energy efficient communication. The agenda of energy efficiency (EE) is also related to Green Communication and that of course is more vigorously related to more extended background from country to universe and from single human to entire animal specie. Today's progression in Information and Communication Technologies (ICTs) have resulted in high CO_2 emissions that have a great impact on today's global warming, which results in more drastic environmental changes. In order to reduce the carbon emission, there is a need to develop and design a more efficient system having less impact on environment.

Main sources resulting in CO_2 emissions are electricity production, transport vehicles, agriculture byproducts and buildings as indicated by International Telecommunication Union (ITU) report [1]. World Energy Outlook (WEO) has estimated, that based on present hike in electrical devices in our homes and industry, the demand for energy will almost be doubled in year 2030 [2]. The proportion of ICTs both in CO_2 emissions and electric energy demands is about 5 percent of the entire world electricity demand [3,4]. The current CO_2 emissions by ICTs is almost equivalent to that produced by airline industry [1,4].

The electricity share for ICTs can be categorized into four sub-branches. Forty percent of total share of electricity is used by Monitors whereas, thirty one percent is used by Telecommunication sector. Servers uses twenty three percent of electricity, while remaining six percent is dedicated for other devices. The telecom sector has further three sub

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sectors i.e. Forty eight percent of the telecom's energy share is used by Fixed-line telecom, twenty nine percent is used by the mobile and the remaining twenty three percent is used by the LAN [1,4]. Therefore, there arises a need for newer wireless communication systems, that must be designed to cope this problem of CO_2 emissions more tactfully.

The theme of this paper is to explore and categorize different energy efficient resource allocation techniques in wireless networks, starting from a contextual overview of green wireless communication. The rest of the paper is organized as follows. Section II reviews the fundamental information required for attaining green wireless communication. This section is followed by the description of energy efficient optimization framework in section III. In the section IV issues related to green wireless network design is reviewed while technologies and standards considered for green communication is discussed in section V. Finally, the article has been concluded in section VI indicating future research directions.

2 Background

The throughput maximization of wireless networks has remained a hot topic in the past decade. The ambiguity in maximizing the throughput of wireless network is the increased energy consumption. Many efforts to improve spectral efficiency have been done, whether it is cellular networks in which the number of base stations are optimized to improve spectral efficiency or the relay system in which relay nodes are incorporated for the same. Also in this regard, different resource allocation techniques have been explored to guarantee fairness and QoS of the users. With the innovation of new techniques like multiple-input multiple-output (MIMO), cooperative transmission and orthogonal frequency-division multiple access (OFDMA), the improvement in spectral efficiency (SE) is complimented. Since the throughput maximization may result in increased energy consumption which has two fold disadvantage in energy aware wireless networks .i.e, reduced battery timings and increased cost. Therefore we will present a detail summary of the efforts that have been made in maximization of energy efficiency of the wireless communication system and will also indicate loop holes and future research directions in this regard.

2.1 Fundamentals of energy efficiency

In wireless telecommunication, the Energy Efficiency (EE) is defined as the number of bits that can be transmitted per unit of energy. Fundamentally, the channel capacity of an additive white Gaussian noise channel is given by the Shannon capacity formulae [5].

$$\mathrm{R} = \frac{1}{2}\log_2\left(1 + \frac{\mathrm{P}}{\mathrm{N_o B}}\right) \quad \text{Bits/Sec/Hz} \tag{1}$$

Where P is the signal power transmitted, B is the channel bandwidth and N_o is the noise power spectral density. The Nyquist sampling theory gives us degrees of freedom per second which is 2B due to which the channel capacity becomes 2BR bits per second. Therefore EE can be expressed as

$$\eta_{EE} = \frac{\text{capacity}}{\text{power}} = \frac{2\mathrm{R}}{\mathrm{N_o}(2^{2\mathrm{R}} - 1)} \tag{2}$$

From Eq. (2), it can be seen that this function is a monotonic decreasing function, since the EE decreases monotonically with R. This means that for obtaining the maximum channel capacity per unit of energy consumed, either transmit with infinite bandwidth or over the longest duration. However, under more practical scenarios of power, modulation schemes, transmission and coding techniques will have a great effect on the above relationship of the EE.

2.2 Definition of green communication

The term "green" in telecommunication is generally used for the measurement of CO_2 emissions that take place while doing communication. However, the more broader definition covers economical aspects associated with the energy savings and increased battery backup along with minimum carbon footprint. Therefore, the energy efficiency for measuring greenness will provide more better insight and we can compare the energy consumption of different wireless systems for its assessment towards green communication.

2.3 Necessity of green communication

Green communication in ICTs means, transmitting and receiving the data with minimal carbon emissions. The research community is stepping towards this goal which is evident from the trends of recent publications in green communication which show that until year 2007, no significant work has been done towards achieving green communication, as the world was unaware of its importance and secondly due to the scarcity of ICTs usage. The awareness slowly persuaded the researchers, thus in less than a decade, the yearly publications increased remarkably in year 2013 as compared to those in year 2007, which is a great achievement. There still exists many open issues which can be resolved to save our environment from harsh Carbon emissions.

Table 1 shows different techniques that have been used in achieving the objective of green communication. The popularity of any wireless communication system is embedded in the users satisfaction therefore, objective of QoS is taken into consideration in [6,9,12], for different wireless appli-

Table 1 Existing survey and review literature for green communication

Ref. No.	Objectives	Technology considered	Radio resource consideration	Remarks
[6]	Power minimization, QoS		No	Focus on energy aware infrastructure and applications
[7]	Power minimization		No	Energy aware fixed architecture
[8]		Optical networks	No	Mixed integer programming used
[9]			No	Cooperative content distribution over WN
[10]		Cooperative communication	No	Vehicular
[11]	Power minimization	Cooperative communication	No	Cellular networks deployment strategies
[12]	Power minimization, QoS	Cooperative communication	Yes	Multi-cellular

cations. To increase the energy efficiency and to achieve the goal of green communication, it is necessary to minimize the power consumption of any communication system which is considered in [6,7,11,12]. The role of cooperative communication in achieving green communication is also very substantial and is explored in [9–12]. Green communication has remained a hot topic for researchers due to its major implications on world environment. There still exists certain unexplored areas that needs attention from the research community e.g., MIMO and CR can be explored while adopting different types of optimization techniques like linear programming, non-linear programming, integer and mixed integer programming etc. For the purpose to have some background knowledge, we briefly present some of the technologies that we will adopt in our research.

3 Energy efficient optimization framework

Optimization is one of major technique through which we can take advantage of limited radio resources by optimally managing it. Recently, efforts have been made by researchers to optimize the different types of wireless communication systems by formulating different types of optimization problems. General mathematical form of the optimization problem is given by

$$\begin{aligned} \text{minimize/maximize} \quad & f(x) \\ \text{subject to} \quad & g(x) \leq \text{b}, \end{aligned}$$

where x is the optimization variable, $f(x)$ is the objective function, $g(x)$ is the constraint function and b is limit/bound for the constraint. For the purpose of illustration and familiarity, we have shown some of optimization problems related to green communication with their objective functions in Table 2.

3.1 EE metrics

Conventional energy efficiency metric covers only a small chunk of power budget which is associated only with the maximization of throughput per unit and disregarding many areas of the whole power budget of wireless network. Thus to avoid this misleading concept, an appropriate metric for energy efficiency must be considered to cover the whole of the power of wireless network should be taken into account. The power budget required to raise the energy efficiency must include, the power produced at the antennas output (include power amplifier losses, power cable losses and air conditioning power consumption at base station, etc), equipment associated with signal processing (encoders, decoders), power associated with EE radio resource management and backhaul power consumption. Thus different bodies have started work on the standardization of EE metric. Some of them work on component level EE metric like European Telecommunication Standards Institute Technical Committee on Environmental Engineering (ETSI-TC-EE) [27] while other work on system level EE metrics. From the information theoretic point of view, the bit per joule metric is used to measure the EE of communication link. Other metrics are bit meter per joule [28], bits per joule per unit area and many more depending upon maximization of EE of different aspects of wireless communication systems.

3.2 EE optimization problem types

Optimization problems can be constraint or unconstraint, depending on the type of applications and these constraint and unconstraint optimization problems can have single or multiple objectives. Enormous efforts have been done by researchers both in multi and single objective optimization types related to EE, that have been summarize in Table 3. Optimization problems can be broadly categorized as linear and non-linear optimization problems. The constraint

Table 2 Objective functions used in increasing EE of wireless communication

Ref. No.	Objectives	Remarks
[13]	Maximization of weighted efficiency	Total weighted system capacity (Bits/Sec) divided by weighted energy dissipation
[14]	Max $\frac{\text{rate x goodput x transmission success probability}}{\text{power}}$	Goodput is the training and feedback mechanism loss. EE is in Bits/Joule
[15]	Maximize rate/energy	Bits/Joule
[16]	In down link max (weighted sum rate)/power and In uplink max rate/power	Bits/Joule
[17]	Minimization of number of relays	Given set of users U, a set of existing BS, charging capacity of relay nodes
[18]	Maximization of weighted EE $\frac{U(P,W,S)}{U_{TP}(P,W,S)}$	Weighted EE is the total no of bits delivered to K users divided by power dissipation. P is power, W is pre-coding coefficient and S is subcarrier allocation. Bits/Joule
[19]	Maximize $U_{eff}(P,A,R,S)$	P is power, A and S is antenna and subcarrier allocation policy, R data rate adaptation policy
[20]	Minimization of total receiving energy $P_r = \underset{W_n, m, K\epsilon\{0,1\}}{Min} \sum_{K=1}^{K} W_k P_k T \sum_{m=1}^{M} f(\sum_{n=1}^{N} W_n, m, k)$	$W_{n,m,k}$ resource unit located at frequency n and time slot m for user K.P_k is the circuit power,W_k is the weighing factor of the user equipment, T is time slot duration and number of time slots
[21]	Cost minimization based on user selection and power allocation Minimize $C_{ij}^{B} = W_1^B f^{+}(Ps_{ij}, Pr_{ij}) + W_2^B g^{+}(Ps_{ij}, Pr_{ij})$	W_1^B and W_2^B are non-negative weights for power and throughput
[22]	$\underset{(\vec{P}_1^0,\vec{P}_2^0,\ldots,\vec{P}_i^0,\vec{P}_L^0)}{Min} \sum_{i=1}^{L} \sum_{j=1}^{N} G_{i,j}$	Reduction of on-grid energy consumed by BS
[23]	Maximize $EE = \frac{\sum_{n=1}^{N} \sum_{m=1}^{M} C_m^n x_m^n}{\epsilon_\circ \sum_{n=1} N \sum_{m=1} MP_m^n x_m^n + P_\circ}$	There is a minimum rate requirement whereas $\epsilon_\circ$ includes power which scales with the radiated power P_{tx}.$P_\circ$ is the power offset
[24]	$P = Min \sum_{n=1}^{N} \sum_{K=1}^{K} \rho_{k,n} P_{k,n}$	$P_{k,n}$ ensures the QoS requirements at the receiving side and $\rho_{k,n}$ ensures one subcarrier for one user
[25]	$Min \{\sum_{v\epsilon V}(P_v^C x_v + P_{v,T(v)}^{RP}) + \sum_{(u,v)\epsilon E} P_{u,v}^{PIC} n_{u,v}\}$	$P_{u,v}^{PIC}$[W] is PIC power consumption from u to v node.P_u^C[W] is power consumption of chassis of node V; $P_{v,T(v)}^{RP}$[W] is power consumption of route processing of node v with traffic throughput $T(v)$
[26]	$\underset{P_{k,n},\rho_{k,n}}{Max} \eta_{EE} = \frac{\sum_{n=1}^{N} \sum_{K=1}^{K} \rho_{k,n}, \gamma_{k,n}}{\sum_{n=1}^{N} \sum_{k=1}^{K} \rho_{k,n} P_{k,n} + P_c}$	Transmission power budget for CR system in down link is in numerator and the circuit energy consumption is taken into consideration

Table 3 EE multi objective and single objective functions

Single objective	[13], [14], [16], [82], [39], [95], [72], [34], [62], [112], [64], [87], [65], [41], [36], [88], [102], [116], [69], [70], [90], [77], [103], [119], [120], [122], [124], [126]
Multi objective	[15], [57], [58], [40], [83], [110], [76], [85], [114], [66], [67], [37], [115], [68], [89], [117], [71], [32], [121], [123]

optimization problem can be both linear and non-linear. The unconstrained optimization non-linear problems can be solved through different methods like Bisection, Newton's method and Gradient methods. The optimization can be differently categorized by taking into consideration different parameters. We have shown a tree diagram in Fig. 1 to categorize optimization problems using type of programming as parameter under the umbrella of green communication.

In [17], green network performance with sustainable energy is analyzed with the limitation on the cost function, that is represented as mixed integer nonlinear programming problem. In [25], the goal is to reduce the power consumed, while taking into consideration the energy of links and nodes. This problem is dealt as general optimization problem. Energy consumption in battery empowered wireless communication systems has very much significance. The researches these days are trying to minimize the energy consumption or in other words trying to increase the energy efficiency of wireless specially cellular communication systems. In [29], it is shown that, since downloading via mobile terminal consumes energy which could be minimized, if the content that is downloaded is common between certain users in the same base station, could be shared. This sharing process increases complexity, which could be minimized by uni-casting or multi-casting the data whereas, the optimization problem has been formulated as a mixed integer non-linear programming problem. In [30], the problem of energy efficiency is taken as non-convex optimization problem by considering the QoS requirements, sum rate power consumption and multiple antenna eavesdropper. By utilizing the properties of fractional programming, the non-convex optimization problem is transformed into convex optimization problem. Similarly by using dual decomposition, each iteration of the proposed energy efficient resource allocation algorithm is solved and analyzed. In those areas of applications where a marginal amount of packet loss is allowed, the energy efficiency can be maximized as explored

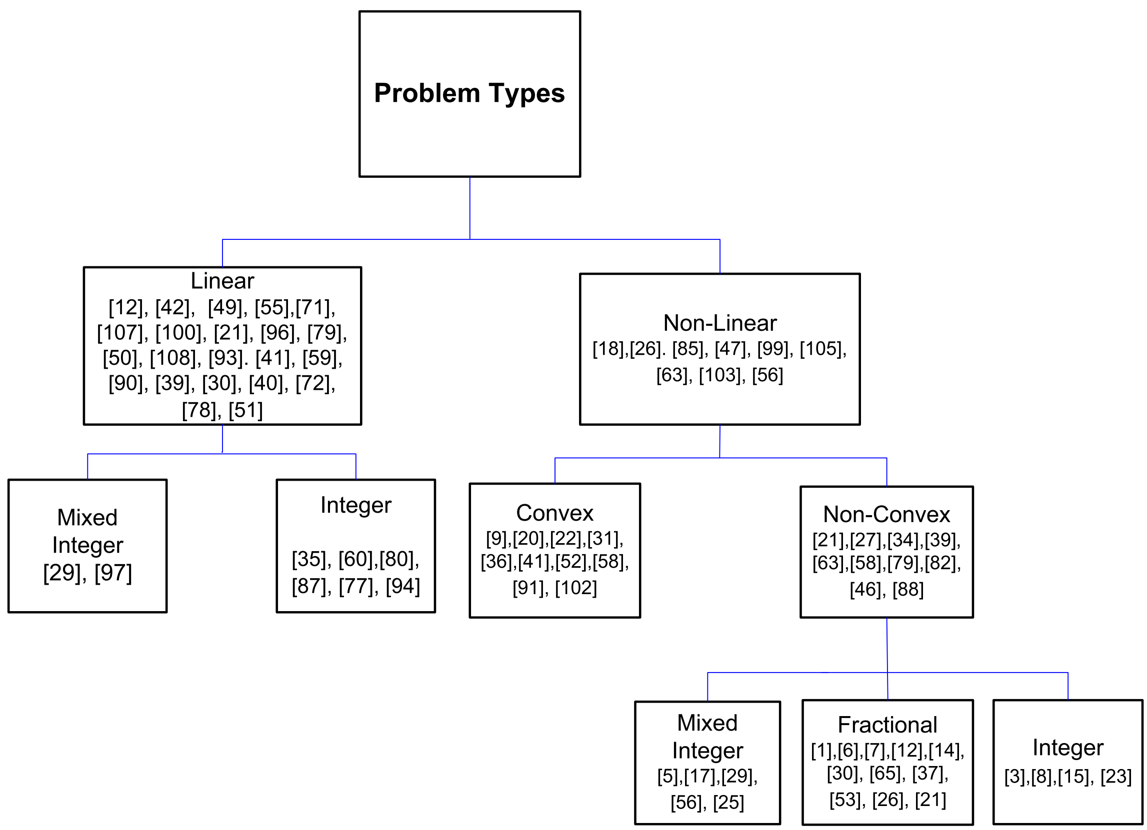

Fig. 1 Problem types in EE radio resource management

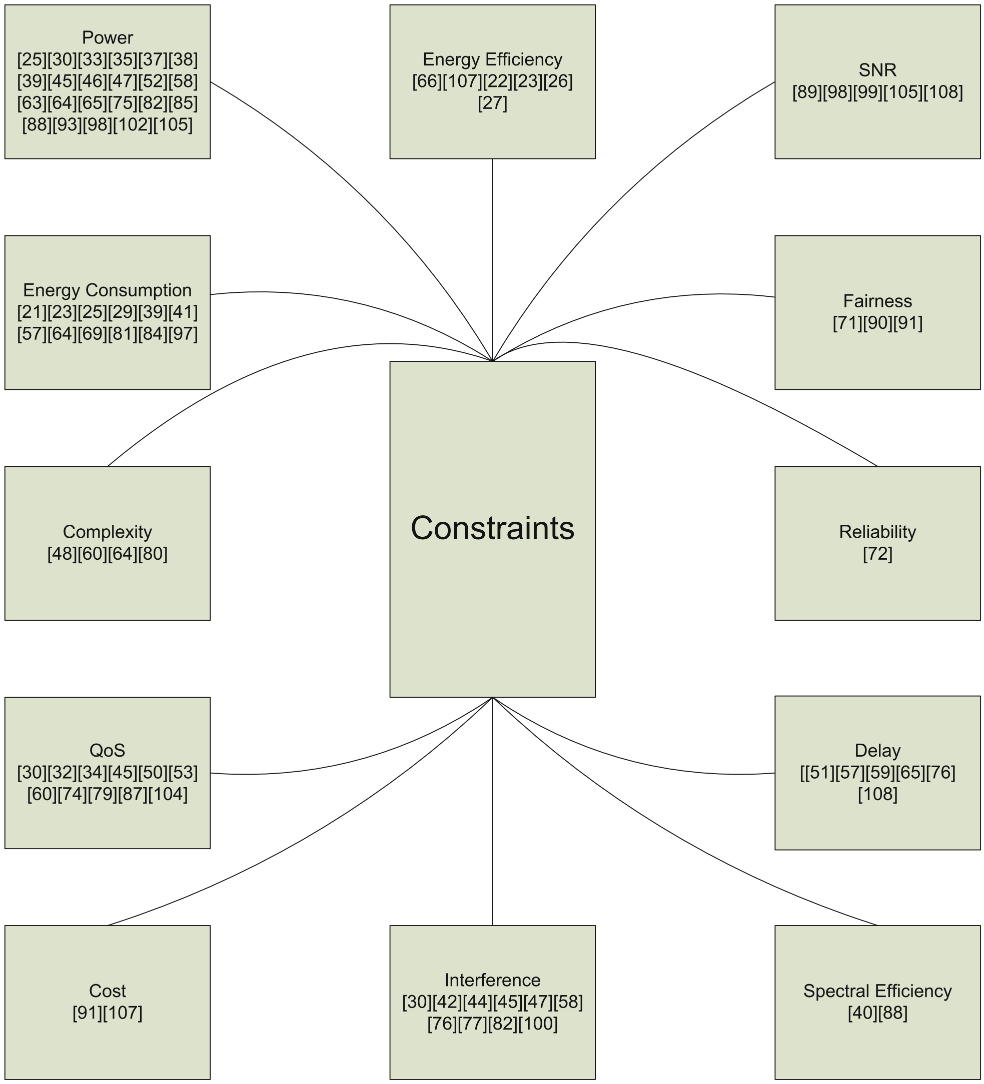

Fig. 2 Constraints in maximization of EE

in [31]. The authors have proposed to drop certain predefined portion of data packets on transmitter side, that reduces the average energy consumed by the system. Both the effects of successive and average packet loss are analyzed, for minimizing the energy consumed. The proposed scheme is also explored using combinatorial programming for optimized channel-dependent dropping threshold and larger users limit. In [32], the authors want to resolve the problem of joint base station association and power control, to cope with co-channel interference in wireless communication systems, which is non-convex and combinatorial in nature and thus, its difficult to reach to an optimal point. Also in this work an attempt is done, to maximize the system revenue by associating the right base station to each mobile station, that will reduce the transmission power.

3.3 Constraints in optimization problems

In maximizing the energy efficiency of a wireless communication system there are many limitations which can be taken into consideration. In order to have a glimpse of the overall picture of energy efficiency a brief summary of these constraints have been shown in the Fig. 2. Since these constraints have a great impact on energy efficiency we will briefly discuss each of these constraints in order to have good understanding of how wireless communication system can be made more energy efficient.

3.3.1 Power

The limited spectrum resources and the huge data rate demands are persuading research community to use Cooperative Communication (CC) as one of the solution to cater the demands of future wireless networks. The key concept of the CC is to retransmit the information that is received from the source and send it towards the destination. Since greater transmit power will achieve greater transmit distance which will create more interference along with the wastage of power as well. Therefore, in reaping the fruits of CC, it is essential to impose limitations on the transmit power. Also the minimization of power is necessary to reduce the overall power consumption of the network such as to achieve the goal of green wireless communication. In [33], the authors explored the energy efficiency in heterogenous networks with the restriction on power consumption. In this regard, the traffic is first split into concurrent paths and then recombined to increase the energy efficiency of the system.

3.3.2 Energy consumption

The drastic evolution of ICTs consequently resulted in huge energy consumption. Amongst other ICTs sectors the mobile wireless communication system has a major share in the overall energy consumption. The advantage of reducing the energy is two fold i.e. first is the battery power-up timing of wireless users could be increased and the second achievement in this regard is a step forward towards green wireless communication. Energy-efficient radio resource management is one of the effective ways to minimize energy consumption of wireless systems [12].

3.3.3 Complexity

The convergence of biggest three sectors i.e. Media, IT and Telecom created an upsurge in the number of systems, technologies, applications, services and users which increases the complexity in the wireless communication system. The complexity generated by the dynamic development of communication system will impair the functioning of the informational ecosystem. The changing operational environment for the communication system, heterogenous infrastructure and the user requirements demands more flexible radio interfaces that are capable of managing such dynamics with less computational complexity [34,35].

3.3.4 QoS

Mostly QoS is guaranteed for the lifetime of a connection, in wired wired communication. While in wireless communication these guarantees are unrealistic due to harsh and unbounded wireless environments. Since wireless links are more prone to errors therefore in those areas of applications only deliverable level of services is ensured under the umbrella of QoS. Therefore, in energy constrained wireless networks the QoS is a big obstacle and needs more attention from researchers while analyzing it in more practical scenarios. For the battery empowered devices, the process of getting energy from the environment is known as energy harvesting. In [36], the author presents the best data transmission strategy for a wireless energy harvesting nodes with a finite battery capacity while maintaining the QoS and energy restrictions. Energy efficiency has a very significant role in those areas of applications that have very limited battery power. In [37], the author has proposed a bandwidth allocation scheme for mobile communication systems with the goal of increasing EE but not at the expense of QoS.

3.3.5 Cost

Detection with the battery-powered sensor networks has high significance in a variety of applications such as environmental monitoring, health, security and surveillance etc. Each sensor node faces very high reservations both on energy and bandwidth and therefore demands system-level approaches to enhance detection performance as the system level cost may increase by increasing the number of sensor nodes. Therefore in such wireless network more choices should be explored to minimize the cost of deployment of such networks.

3.3.6 Interference

Interference is one of the most common criteria for designing an efficient wireless communication system. Interference generally is of two types i.e. Short-Term Interference which is usually random, and relatively very strong, causing system outage while Long-Term Interference is the one which is present for a large fraction of the time and the system must be designed to operate through it. If the interference is noise like, that will mean randomness in amplitude and it will be non frequency selective. Many approaches like power control etc has been done to limit the interference between certain limits but there is still quite a room available in addressing this issue in energy constrained wireless networks. In [38], the maximization of energy efficiency is considered under constraints on total power and interference. The authors have shown an energy efficient system by adopting joint distribution resource allocation. Obviously, the energy efficiency is an important criterion for good cellular system where there is limited battery power available. Inter Cell Interference (ICI) is a key factor in radio access network. In [39], the agenda of reducing ICI is considered to increase the energy efficiency. Interference in a wireless communication system is undesired and always degrade the performance. But in [40], interference is shown to increase the desired signal strength in some scenarios and thus provides additional signal power. The scenario taken is down-link cellular system where interference is used to increase the system power efficiency.

3.3.7 Spectral efficiency

The optimized use of spectrum or bandwidth is called Spectrum Efficiency (SE) such as, maximum amount of data is transmitted with lowest number of errors. SE is a widely used performance indicator for the design of wireless communication systems. Most of the time, the spectrally efficient systems perform well in high power regimes, that result in more energy consumption, thus deviating from our goal of energy efficient wireless communication systems. The SE of a wireless communication system is determined from the channel characteristics which relates the transmitted and received signals. In general, the wireless communication channel is very complicated. It depends on transmitt/receive signal characteristics and the propagation characteristics of the antennas. For this reason, the multiple-input multiple-output (MIMO) systems, recently have gained much popularity due to its ability to increase the spectral efficiency in wireless communication systems.

3.3.8 Delay

For real time wireless communication systems applications average packet delay is an important service parameter. In a communications system, propagation delay is referred as the time difference between, the signal transmitted from the source and the reception at sink. This difference may range from a few nanoseconds to milliseconds in wireless communication systems. Therefore, it is vital to devise advanced transmission schemes that may jointly address the goal of energy efficiency, reliability, high rates and low delay. These goals can be accomplished through efficient resource allocation and may also require collaboration between physical and upper layers. Transmission power is also one of the parameter which may lead to maximize the energy efficiency of wireless communication system. In [41], the same goal of reducing transmission power is explored in a scenario of transmitting a video sequence over a wireless channel. At the source coding level error resilience and concealment techniques are used to reduce the transmit power at physical layer. While restricting the delay and distortion, the optimization problem is formulated for minimizing the transmission energy.

3.3.9 Reliability

The reliability in wireless communication system is use to ensure the information reception from the source to destination. Reliability can be achieved by increasing the transmission power which will decrease the energy efficiency. Various techniques like cooperative communication can be used to increase the reliability in energy constrained wireless communication systems.

3.3.10 Fairness

Fairness in wireless communication is the terminology used for equal rights of using the resources among users. In unconstrained resources, fairness can be achieved by maximizing the power. However, in energy constraint wireless network the fairness can be achieved through efficient and fair resource allocation techniques. The constraint of fairness has been considered in [42].

3.3.11 SNR

The desired part of a received waveform is called the signal and the undesired part of a received waveform is called the noise. Signal-to-Noise Ratio (SNR) is the ratio of signal power to the noise power. Since, the fluctuations arises in signal and noise power from time to time, thus most of the time SNR value is taken as average SNR. Since the power is one of the major constraint in energy constraint wireless networks thus optimal SNR needs to be devised in overcoming this constraint.

3.3.12 Energy efficiency

With immense growth of high-data-rate applications, more and more energy is dispensed in wireless communication networks to ensure the quality of service. Therefore, remarkable attention has been given to energy-efficient communications under the context of restricted energy resources and eco-friendly transmission behaviors.

4 Green wireless network design

Due to increased dependency on wireless technology, the research community is pointing towards the improvement of energy efficiency at every level of operation whether, it is protocol stack, system architecture, physical or operational management. In this section, we will address the green wireless network design issues associated with architecture, network management and radio resource management.

4.1 Green network architecture

Architecture of the green network design can be divided into the following categories.

4.1.1 Radio component

The base station has major portion in the energy expenditure of the wireless communication system. There are three major components in the base station i.e. baseband unit, radio and feeder network. Of these components, the radio almost consumes 80% of the base station energy and in this share almost 50% is use by the power amplifier [43]. The nonlinearities associated with the power amplifier results in the degradation of the energy efficiency thus causing additional overhead. Similar is the case with the modems of the mobile stations where power amplifier uses most of the power. The two important characteristics of power amplifier is linearity and efficiency. By increasing the input signal power to the Power Amplifier (PA), the efficiency is increased but on the other hand the PA becomes more nonlinear and more distorted. Reduction in efficiency decreases the system energy efficiency while nonlinear amplification results in performance degradation. Thus research on material, architecture and signal processing algorithms for increasing the PA efficiency has attained much improvement. The direct method to reduce the nonlinearity and inefficiency issues of PA is to use the special architectures for amplification. Few of the transmitter architecture techniques are linear architecture, corporate architecture, stage bypassing and gate switching, Kahn technique, Outphasing and Doherty technique, etc. [44,45]. The second step in reducing the nonlinearities and inefficiency is through signal processing techniques which includes Input backoff, Linearization, Peak to average power reduction method and SE improvement methods, etc. Finally these PA nonlinearity issues can be further improved through using efficient network protocols.

4.1.2 Network operation and topology

As we know that the base station is one of the most power consuming component of the whole wireless cellular network. Various aspects for energy minimization of the Base Station (BS) have been explored. Energy efficiency of the BS can be improved substantially through modular design and some how reducing the feeder cables length. This may also be accomplished by placing the radio transmitter closer to the antenna. Designing of network operation also include the size of the BS which if smaller might need less energy for cooling purposes. The topological aspect of the network also increases the EE. If properly designed, the number of BS can be reduced without decreasing the coverage area and QoS. Other techniques that can be used for increasing the EE of the BS is through transmitter diversity, receive sensitivity and reducing the distance between the BS and MS [46]. Femto-cell and pico-cell technologies can be used for decreasing the power usage of the system without degrading the capacity and QoS.

4.1.3 Incorporation of alternate energy

The design of green network architecture should also include the replacement of alternate and cheap energy resources for the operation of base station. These resources may include wind, solar energy and fuel cells instead of conventional more expensive diesel energy whose transportation charges to far sites impose additional charges. Also new energy harvesting techniques for mobile station must be adopted for the replacement of chargeable batteries in order to enhance the EE for more green network design. In [22], hybrid energy supplies is explored while keeping a check on temporal and spatial diversities which is a problem of multi stage energy allocation and multi base station energy balancing.

4.2 Network management

The design of wireless network for green communication requires that the network should be skilfully managed to minimize the energy consumption of the overall wireless system. For that matter, it is necessary to understand the network nodes structure including the backbone network thus improving the coordination for improved wireless network energy efficiency. This understanding will help in establishing autonomous EE optimization network which will adjust itself according to the day to day traffic variations of the load. Network management algorithms to this effect have significant importance in design of EE network management [47]. It is also necessary to configure and tune the radio network nodes for cooperation and interaction between the network elements, thus increasing the overall energy efficiency of the network.

4.3 Energy efficient radio resource management

As discussed earlier, the upsurge in services demands poses great challenges for future wireless communication. One of the biggest obstacle in coping these challenges is the scarcity of the radio resources. Thus, efficient radio resource management is one of challenging task that needs to be encountered by the researchers. Energy-efficient radio resource management is one of the effective ways to reduce energy consumption of wireless systems. The term Green Communication is a terminology used by the ICTs sector for that particular communication which take into consideration carbon emissions that take place while transmitting and receiving information. The Global e-Sustainability Initiative (GeSI) reported that CO_2 emissions made by ICT sector is about 150 mega ton per year that will exceed to about 350 mega tons per year in 2020 [7,48]. Figure 3 shows CO_2 emissions contribution of different ICTs sectors in year 2002 and its comparison in year 2020.

To achieve this goal of low CO_2 emissions, it is essential to reduce the energy consumption thus by increasing the energy efficiency of the communication system. Energy efficiency in telecommunication can be defined as increasing the

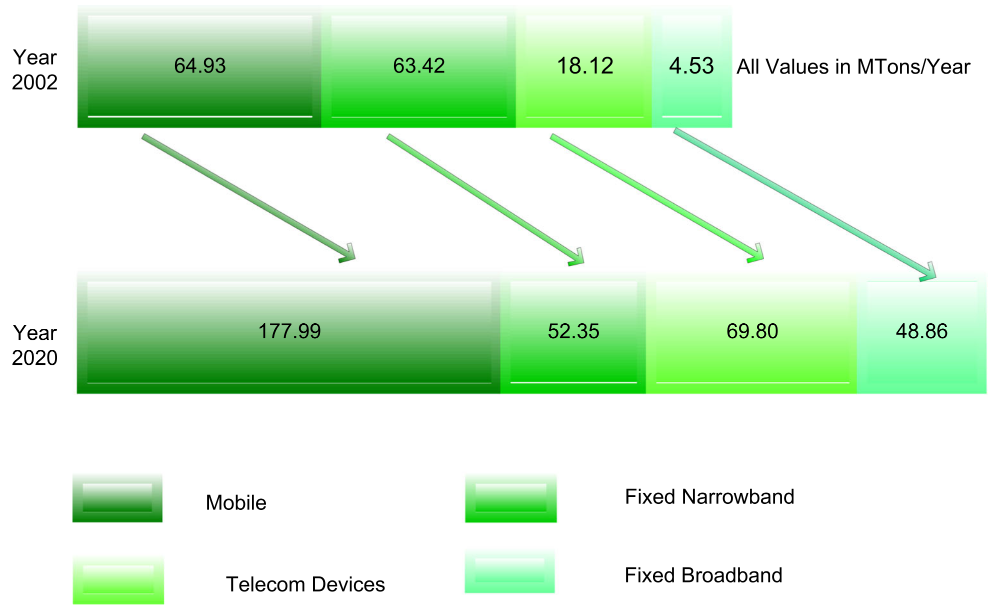

Fig. 3 CO_2 Emission in Mega tons per year estimated by GeSI

number of transmitted bits per joule of energy. This goal of increasing the energy efficiency may deteriorate the QoS of the system. There are various techniques involved in increasing the energy efficiency i.e., efficient resource allocation schemes, cooperative communication, etc. Cognitive Radio (CR) and Device-to-Device (D2D) communication are two new emerging fields with the help of which the energy efficiency of the system can be increased. Thus, in the above context of reducing CO_2 emissions, there is a need to devise intelligent resource allocation schemes for wireless communication systems with relaying capabilities. Radio resource management is used to increase the energy efficiency in [49], in green networks while restricting the QoS.

4.3.1 EE resource management in homogenous cellular networks

Energy Efficient resource management in homogeneous cellular networks consisting of large macro-cell base stations designed for provisioning of seamless mobility and widespread coverage, have a great impact on the overall energy consumption of the system. In [50], different network deployment strategies to increase the energy efficiency of cellular networks have been considered. Based on the analysis of these deployment strategies, it is shown that micro-cell based network having large number of low power stations is the most energy efficient scheme. Likewise in [51], greening of cellular network is portrayed through interference management while deploying spatio-temporal power sharing policies.

4.3.2 EE resource management in heterogenous cellular networks (HetNets)

In wireless cellular networks, HetNets consists of different size of base stations like miro, pico and femtocells interconnected with each other for increasing the network capacity in hotspots where the traffic demands are very high. Due to low path losses between the user and BS, the data rates in downlink in small micro-cell is quiet high. But by increasing the number of small cells in an area increases the interference and thus minimizes the EE and SE of the overall wireless cellular system. The other drawback associated in the deployment of the HetNets is the additional power that might result due to additional BS hardware related expenses. So, it is essential for the sustainability of HetNets that it must provide the additional amount of gain in the EE of the over all wireless system in-order to overcome the additional energy expenditures that it utilizes.

4.3.3 EE resource management in cooperative networks

Energy efficiency and performance improvement can both be achieved through cooperative networks in wireless communication systems. Through incorporation of relay nodes, more source node connections are established thus data can be delivered to the destination through multiple wireless links. Diversity gain can be achieved due to independency of different fading channels through which SE can be improved. This reduces the transmit time of the data thus reducing the energy consumed. Thus if advanced resource allocation schemes are applied energy consumed can be minimized fur-

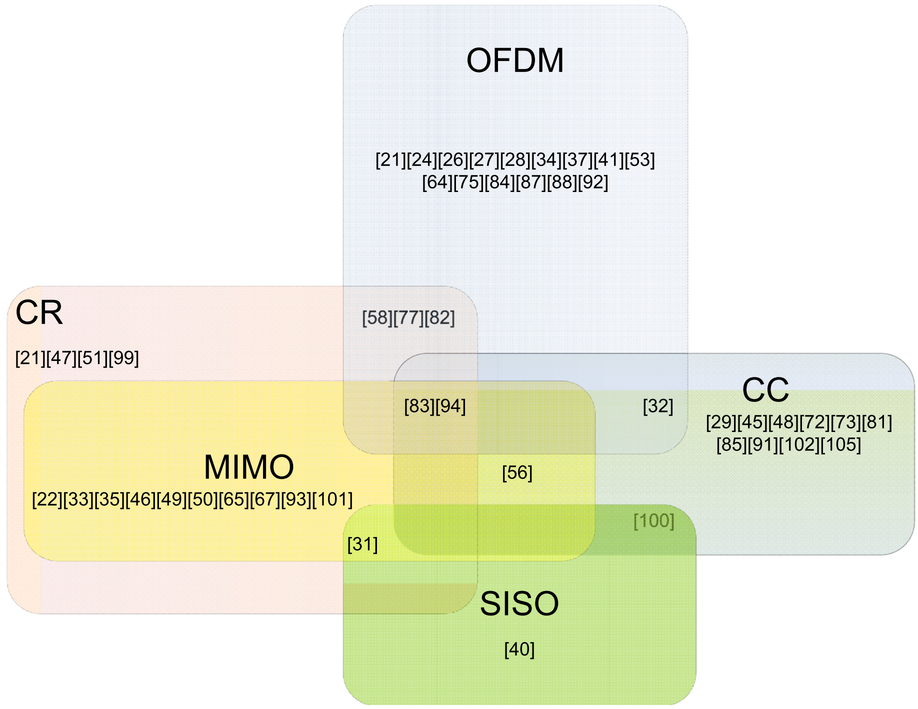

Fig. 4 Technologies used in green communication

ther. Transmission period of a relay typically consists of two phases i.e broadcasting phase in which data is sent by the source node over the air that may be received by either relay node or by both relay or destination node. The other phase is multiple access phase the data is sent by the relay node or both the source node and relay node to the destination node. There are two major transmission schemes at the relay node which are amplify-and-forward (AF) and decode-and-forward (DF). Also in literature, there are two types of relay systems [52], pure relay systems and cooperative relay systems.

(1) *Pure relay system* In purely relay system, the relay nodes only facilitate the data transmission. In these system the problem is the design and configuration issues related to number and efficiency of the relay nodes. In [53] the tradeoff between EE and SE in pure relay system has been studied to maximize the EE while assigning optimal power to the relay nodes. It is also shown that data rate and energy consumed by the purely relay system are influenced by the relay nodes location, transmission strategy of nodes and data rate of each node. While, these schemes shown in [53] has major implications in increasing the EE but such proposed schemes are very complex and might not be used in more practical scenarios. Enormous efforts have been done in literature whether it is two hop scheme, best relay node selection or multiple node selection scheme. It has also been shown that due to cooperation overheads, the EE can not be increased by increasing the number of relay nodes.

(2) *Cooperative relay system* In cooperative relay system, all the nodes acts relays as well as the information sources. Thus resource management optimization is more complex as compared to pure relay system. Here, one of the biggest problem is the separation of the information generated by the individual node and data received from the other nodes. Along with this, the optimal vicinity selection for best EE is also a critical issue in large number of relay nodes and for both these issues cooperative relay system has widely been studied. A network with two user in [54] is taken into account to maximize EE of each user in a distributive manner by assigning optimal power to each user. Power minimization under the constraint of data rate of each node has been done in [55]. Also efforts have been done in user pairing and subcarrier optimization while, taking into account the transmission errors.

5 Technologies/standards considered for green communication

Energy efficiency can be increased through various wireless technologies. Some of these technologies/standards are shown in Fig. 4. Following is the summary of those technologies/standards.

5.1 Green OFDMA networks

Orthogonal Frequency Division Multiplexing (OFDM) is a blend of modulation and multiplexing which is used to increase the bandwidth and data capacity of wireless communication systems. This is done by dividing the bigger channels into multiple narrow band channels of orthogonal frequencies that can simultaneously carry different parts of message. The orthogonality of these channels ensures the interference avoidance, by having no overlap, despite the close locations of these channels. Following is the elaboration of different scenarios in OFDMA networks.

5.1.1 Centralized single cell scheduling

Scheduling is the process of handing over the resource to a particular user. By centralized scheduling it is meant that the base station is responsible for scheduling process both in uplink and downlink communication. All decisions are first made at the BS and then conveyed to the mobile users. In instantaneous centralized scheduling at each instant of time either sum-rate or any other utility is maximized. The benefits of random channel variations are utilized by the BS by doing more efficient resource allocation. The distributive nature of scheduling in the uplink makes the scheduling process more complicated in comparison to downlink scheduling. As every user has to assign its own power in uplink and in downlink the BS is centralized body responsible for scheduling. In [56] the scheduling process and MIMO pre-coding techniques are utilized. Here also the constraint over Qos is made while increasing the objective of power efficiency.

5.1.2 Distributed scheduling

Base station in centralized scheduling is the body responsible for resource allocation decisions. Since more bandwidth hungry services are the demands of the present and future wireless systems, thus there is a need for mobile stations, that can support multiple standards. Also, along with enhancement of scheduling techniques with in the same network, there is a need to have research in heterogenous networks for optimization of resources allocation.

5.1.3 Multicell scenario

The interference issues in single cell scenario in OFDMA networks in intracell is covered by the orthogonality of the subcarrier. Whereas in multicell scenario, a lot of work has been done in the research to reduce the effects of interference. For that matter, several techniques like fractional frequency in which a cell is divided internally for the same frequencies to be reused in all cells has been survey in the literature. The technique of scheduling is considered in [23], where the objective is to increase energy efficiency, while satisfying constraint over QoS. The lagrangian duality theory is utilized in achieving this goal in multi-user OFDMA system.

Like in any other wireless communication, EE in OFDMA plays a vital role. In [13], the objective of energy efficiency in the energy constrained OFDMA system is considered, which is formulated as a non-convex optimization problem. This non linear fractional programming problem is transformed from non-convex to convex optimization to achieve the optimal value. Again in [16], the problem of increasing energy efficiency in OFDMA systems in frequency selective fading channels is explored, where system complexity is also taken into consideration. In [18], the goal of increasing the energy efficiency in OFDMA system, is taken into consideration in limiting factors of power consumed and data rate. By using fractional programming, the problem is transformed into convex optimization problem from non-convex optimization. In [19], the goal of energy efficiency in OFDMA system is again explored but this time the limitations is imposed upon power consumed by the system and QoS while considering the imperfect channel conditions. Fractional programming is used for non-convex optimization. The reduction of individual user equipment is taken into consideration in [20], while considering total energy into consideration in OFDMA system. The optimization problem is non linear Integer programming in nature. Cooperative base station in OFDMA system is considered in [30]. The objective of this research is to increase the energy efficiency under the constraints on power consumed and data rate. The concept of fractional programming is used to make the problem as convex optimization problem.

In increasing the bits per joule, researchers have shown OFDMA as the best technology. The energy efficient power allocation problem portrayed for a general SISO-OFDM down-link system in [57], is transformed from non-convex optimization to quasi-convex optimization problem. The algorithm proposed in this research is shown as more energy efficient power allocation while restricting the spectral efficiency at some threshold. In [58], author uncovers the advantages that are associated with the opportunistic relaying and single frequency operation in SC-FDMA uplink. With the assumption that channel quality information is available, the authors have shown that apart from the direct transmission, the first-hop quality awareness joint dynamic resource allocation scheme is more energy efficient.

Efficient power allocation schemes can considerably increase energy efficiency of a wireless communication. A joint framework for both power optimization and adaptive modulation for uplink SC-FDMA access system has been explored in [59]. Here, the authors have adopted a new technique for the solution of allocating multiple sub-channels to a user in SC-FDMA. The optimization problem is formulated as binary integer optimization problem which is then transformed into continuous space canonical dual problem. The power optimization problem in SC-FDMA is again considered in [60], where the power is optimized for multiple sub-channel allocation for a user in SC-FDMA. The power minimization in presence of outdated channel state information in OFDMA system is considered in [61]. The problem is formulated as a convex optimization problem. In [62], the author investigated the throughput improvement while dispensing same unit-energy consumption in OFDM-based CR systems. Under the multiple constraints of total power, rate and interference the problem is formulated as non-convex optimization problem to find the optimal solution. In [63], the power allocation with delay outage probability for frequency selective fading channels in multi-carrier link is explored. The relationship between the achieved affective capacity and the system total power, constitute the system energy efficiency. The problem is formulated as quasi-concave function whose achieved optimal results is obtained through fractional programming.

In [64], for attaining EE in OFDMA system, a resource allocation scheme is proposed using correlated equilibrium. Using the linear programming duality, the author has made a balance tradeoff between EE and fairness. EE of OFDMA network is again reflected in [65]. The authors here proposed a sleep mode under which some components of transmitter is powered off to save energy. To minimize the energy consumption a mix integer programming problem is formulated while satisfying average data rate requirements. An iterative solution is proposed which shows good results under low load conditions.

In [66], the EE power allocation for more complicated scenario of OFDM-based CR network is explored. A convex optimization problem is formulated that includes effect of subcarrier availability by incorporating linear average rate loss function in the optimization objective. The problem of admission control and cross-layer resource allocation in OFDMA-based femto-cells is explored in [67]. A co-tier and cross-tier interference based unified model which also takes into account the rate and blocking probability requirements of users of both tier is developed. While maintaining the QoS the proposed joint admission control and power adaptation has significant power savings. In [68], the authors have presented an EE scheme, for uplink cellular OFDMA transmission using time-averaged-bits-per-joule metrics. In this scheme multiple users communicate to a central schedular via frequency selective fading channels with high energy efficiency. In [42], the authors focussed on the tradeoff between the EE and SE in down-link OFDMA networks. For that matter a trade-off framework is developed while considering the over all SE, EE and per user QoS. This framework shows that EE is strictly quasi-concave in SE. In [69], EE is again maximized in uplink OFDMA cellular system networks. The authors have proposed non-cooperative base station controlled resource allocation scheme, in which each base station in each cell jointly executes subcarrier assignment, power control and modulation adaptation.

Energy efficiency is critically important in those areas of applications where re-charging of batteries can not be done in a convenient manner. In [70], the authors have taken into consideration one such application of wireless sensor networks. Here the author considers the energy efficient resource allocation for a simple time division multiple access scheme, that minimizes a general cost function for average user power, while maintaining fairness. In [71], the maximization of user's signal to interference plus noise ratio and EE in bits per joule, is taken into consideration, in a non-cooperative resource allocation, in a multi-cell up-link OFDMA system.

5.2 EE MIMO techniques

MIMO is a smart antenna technology which is used to enhance system performance of the communication system while using multiple antennas at both the transmitter and receiver ends. Since MIMO technology can accommodate high data throughput and extended coverage area without any additional power or bandwidth, due to which it has gained significant importance in wireless communications. MIMO technology is also useful in combating multi-path fading and by using diversity the capacity of the wireless channel can be increased.

In [14], the increase in energy efficiency in MIMO systems is considered while doing the antenna optimization for the best match, keeping the limitations on the total power of the system. This increase in the energy efficiency is formulated as non-linear non-convex problem in the presence of inter channel symbolic interference. Again in [24],the objective of EE is considered while restrictions are made on the total power. This is taken as non-linear non-convex optimization problem, while optimizing the antenna in MIMO system in presence of inter-channel interference. In [72], the optimization of energy efficiency which is a non-convex function of power in uplink virtual MIMO system is explored. The energy efficiency for MIMO Broad Cast channel is characterized in [73], for which practical power model i.e. number of active transmit antennas is taken into account. The problem is formulated as fractional programming problem and it is transformed from concave to convex optimization problem by using KKT conditions to find the optimal antennas configuration for minimum energy consumption. In [74], again the notion of energy efficiency is taken into consideration using spatial class of modulation. This problem is formulated as the convex optimization using MIMO techniques. In [34], first the performance of the Cooperative MIMO wireless sensor networks is analyzed and the total energy consumption is categorise into two sub categories as inter-cluster and intra-cluster energy consumption. Based on the performance metrics, a new sleep mode strategy for node is devised where the overall system energy is minimized by coordinating the number of active sensor nodes and inter-cluster transmitting energy consumption. In [75], an energy efficient power allocation scheme for employing physical layer security in multi-antenna down-link system is explored while restricting the power and delay. For realization of adaptive transmission, the switch beamforming is employed that shows the importance of channel state information in multi-antenna down-link networks.

Due to growing interest in energy efficient communication system, the authors in [76], have investigated the relationship between Energy Efficiency (EE) and spectral Efficiency (SE) in MIMO system. Both semi-correlated fading channels and independent Rayleigh channels are taken into account to have a better vision of the practical MIMO systems. Based on this, an upper bound on EE as a function of SE is derived that can be used to see the influence of SE on EE. With this upper bound, the authors have shown that EE can be maximized by optimizing number of antennas either on transmit or receive side for a given specific value of SE. In [77], the EE and SE trade-off in up-link multi-user cellular virtual-MIMO system is taken into consideration with decode and forward protocol. In [78], an optimization problem of minimizing the total energy consumption, for resource allocation in relay-enhanced bi-directional MIMO-OFDM network is considered. Sub-channel assignment, phase duration, power allocation and QoS is taken into account in formulation of optimization problem, for the system consisting of a single base station (BS), multiple fixed relays and multiple low mobility UE's. Lagrange dual method and sub-gradient approach is used to solve this problem.

5.3 EE cooperative communication

Cooperative communication is a near past technological development in wireless communication. It is based on relaying techniques which has substantial impact on throughput maximization and coverage expansion [79,80]. For increasing the performance of the wireless communication system various relaying techniques for example decode and forward (DF), amplify and forward (AF) and incremental relaying etc can be utilized [81]. In AF scheme, the relay between transmitter and receiver simply gets the signal, amplifies it and sends it to the receiver while in DF scheme, the relay gets the signal from the transmitter then decodes it and then retransmits the re-encoded signal to the receiver. This idea can be extended further to multiple relays between transmitter and receiver in-order to improve the performance and reliability of the network. Although the reliability of the wireless system increases with the multiple relays, but at the same time results in more system complexity and complications. Therefore, the multiuser cooperative communication system must be devised with relay assignment task and power control, to minimize the overall system energy which is a difficult task to accomplish. Also, special optimization procedures should be employed to reach the optimal solution.

The ego of EE is cited in [82], where an energy efficient optimization framework for down-link cellular system in frequency selective fading channels is assumed. The authors have shown that coordinated cellular system in medium and large cell size is more energy efficient than an un-coordinated system. In [83], the power allocation in cooperative communication (CC) is explored. Since availability of Channel State Information (CSI) is necessary in CC, which cannot be estimated very accurately. This research proposes an optimal power allocation scheme in CC in presence of imperfect CSI. In [84], the authors have proposed a centralized framework of optimization, that takes decisions based on CSI. The problem is approached using dual optimization framework. In the proposed algorithm the transmit power of the system is minimized through best relay selection and optimal power and subcarrier allocation under the constraints on data rates. In [85], the EE in end-to-end multi-hop system with one sender, one receiver and multiple relays is taken into account. In this work the authors have proposed a globally optimal link adaptation and relay deployment strategies for energy efficient multi-hop systems. Multi-mode terminals supporting wide range of standards require additional cost which can be addressed using more flexible interface. However, energy efficiency is the major hurdle in successful deployment of these reconfigurable radios. In [86], the goal of EE is taken into account by minimization of power consumption in cooperative wireless communication while guaranteeing reliable transmission using multiple active transmission pairs. The problem is formulated using combinatorial optimization problem by jointly taking power allocation, relay assignment and transmission mode selection for which an iterative solution framework is made to obtain the optimal solution. In [87], the relay assignment and EE are again investigated for low power scenarios while considering a time division duplex operation in a system with a source node, destination node and a single relay. A comparison, for energy consumed by a single bit transmission is done in Amplify and forward, decode and forward and block markov coding relay schemes. In [88], the EE in two sources nodes with distinct QoS is considered, in contrast to conventional single transmitter, receiver and relay nodes. The authors formulated a joint optimization problem, which results in small energy consumption while satisfying the QoS of both the nodes. The significance of cooperative communication is further complimented by the fact that it provides the spatial diversity without increasing the number of antennas. In [89], the authors present energy efficient node-disjoint multi-path routing, for source-destination pair by joint route construction, power allocation and relay assignment schemes.

In [90], the authors consider three nodes two-way relay system with digital network coding. The optimization problem is formulated for both the channels with static and dynamic gains, to minimize total energy consumption while ensuring queuing stability at all nodes, for a given pair of random packets arrival rates. The value of any service, is an important factor which should be taken into account and the authors in [21], have tried to minimize such cost keeping the constraints on transmission power, Qos and inter channel symbolic interference in cooperative communication scenario using multi objective optimization. In [91], the energy model of multi-hop cooperative MISO is formulated, for discovering the optimal hop distance and number of operating nodes, for minimizing the per bit energy consumption of a high node density network. In [92], an optimization problem is formulated, for which data is taken from scattered sensor nodes. Maximum likelihood estimation from statistically independent sensor nodes is used for ordering the transmission from these nodes to reduce transmissions from these sensor nodes.

5.4 Cognitive radio

Frequency spectrum is a precious natural resource due to its vast applications in wireless communication system. The use of this resource is under the obligation of regulatory authority, who under the globally fixed spectrum management, assign fixed chunk of spectrum inflexibly to the licensed users. If analyzed, these assigned frequency portions are under-utilized and show many vacant bands. While on the other hand, the demand for usage of frequency spectrum by service providers is increasing day by day. This under-utilization of frequency spectrum can be overcome by use of Cognitive radio technique, with the help of which those portions of free frequency spectrum can be accessed dynamically [38].

Cognitive radio (CR) is a type of wireless technology in which a transmitter or a receiver can cleverly detect those communication channels that are occupied and those that are not, and immediately switch over into free channels whereas keeping itself away from occupied ones. In this way, the radio frequency spectrum is efficiently utilized while keeping the interference low to the licensed users. Therefore, a secondary user which do not have any royalty, can take the advantage of this unused frequency bands under the conditions of, not causing any interference to the primary user. Therefore, it is very critical for the cognitive radio user to sense these spectrum holes reliably and efficiently [93], to get rid of interference. In [94], the authors have elaborated the spectrum sensing techniques in cognitive radio sensor networks. The obstacle in achieving the goal of efficient spectrum sensing is fading, shadowing and time dependency of wireless channels, resulting in low signal to noise ratio at the input of cognitive radio user that leads to activity of false detection of spectrum hole. In [15], the author maximizes the throughput and energy efficiency of the cognitive radio network by performing scheduling. This objective is dealt as non-linear integer programming problem while imposing limitation on the energy consumption. The objective of energy efficiency in cognitive radio networks is also considered in [26]. Here, EE under the constraints over transmission power, interference and traffic demands is formulated as mixed integer programming problem in OFDM systems.

In CR systems, most of the research is done on interference and spectrum management whereas the energy efficiency is still a hot topic as for as the heterogeneous cognitive radios with femtocells are concerned. In [95], the spectrum and power allocation are discussed for attaining energy efficiency in cognitive radio networks with femtocells. A gradient based algorithm is proposed to get the energy efficient allocation. The objective of energy efficiency in [96], is explored in small cell access points (SAPs) in cognitive radio networks where they cause in additional energy consumption in order to satisfy the user demand. Utilization of sleep mode strategy in these SAPs is shown to have better energy efficiency while restricting the interference and power consumed. The objective of the research in [97], is the multiple target tracking in cognitive radar system. Here the constraints are delay and doppler's spread. Bayesian sequential filtering is used to estimate the targets and the channel state. In [98], the dimension of energy efficiency in cognitive radio networks is studied. Since efficiency of wireless communication system is increased by incorporating cognitive radio capabilities in that system while doing so requires energy efficient cognitive radio's which itself requires different tradeoffs of increased hardware complexity and design. Energy efficiency in CR sensor networks can also be raised through skillful selection of sensing and decision nodes as specified in [35]. Formulated as the convex optimization problem, joint sensing node and direct node are analyzed to minimize the energy consumed by the sensor nodes. In [99], the readers have surveyed the resource allocation in Cognitive radio sensor networks. In CR networks the secondary users co-existence may degrade the system energy depending upon the knowledge of channel state information. In [100], the authors have pointed out one such scenario in MIMO cognitive radio networks. It is shown that to minimize the system energy consumption, while taking into consideration the SU's rate and PU's interference, time allocation for SU's and beamforming vectors should be optimized.

One of the main feature of the CR is the spectrum sensing. The SU frequently senses the channel to ensure PU protection at the expense of some energy consumption. Sharing sensing information by SU's make sensing more robust and error free. In [101], the EE using cooperative sensing in CR is explored. The optimization problem formulated is multi-objective i.e. to minimize the spectrum sensing duration thus maximizing the data transmission time and the other objective is to minimize the energy consumed. A heuristic approach is adopted to reach the optimal energy efficiency using outer linearization technique. The slogan of EE is again raised in [102], where the platform selected is wireless cognitive radio ad hoc network. The problem of minimizing the per bit energy consumption for the whole set of available subcarrier for each user is formulated as multi-dimensional constraint optimization problem having the restrictions on QoS and power. The study have shown that energy efficiency can also be increased by properly managing the energy consumed by the spectrum sensing. In [103], the effect of sensing energy cost, on end-to-end distortion of parallel gaussian sources is formulated as distortion minimization problem while keeping the restrictions on the energy budget for both sensing and transmission. Optimization of the packet size in CRSN is explored in [104], where acceptable interference level of the PU and maximum acceptable distortion between the sink and the source has been taken into account.

5.5 EE SISO

SISO (single input, single output) refers to a wireless communications system in which one antenna is used at the source (transmitter) and one antenna is used at the destination (receiver). Due to the involvement of one antenna SISO systems are less complex in comparison to MIMO system. Since the transmission over MIMO require more antennas, so utilizes more circuit power. Therefore energy efficiency can switch between MIMO and SISO depending upon the operating conditions [47]. Ideally, Shannon capacity of SISO channel is dependent upon bandwidth, transmit power and interference. To achieve maximum SISO capacity for SISO channels, it is essential to increase bandwidth and power or reduce the noise level, but in practical scenarios there are many limitations on them.

5.6 EE femtocells

Femtocell is a low-power wireless base station for cellular access, designed for indoor applications home or small office. A femtocell is connected to a broadband and is fully equipped to provide complete voice and data services to cell phones and PDAs that have been registered with in a limited range. The maximization of throughput in femtocells while keeping the restrictions over the total power is explored in [105], where the author has tried to maximize the throughput by joint power adaptation per subcarrier.

5.7 EE LTE/3GPP

The 3rd Generation Partnership Project (3GPP) is an alliance between certain groups of telecommunications associations that are known as the Organizational Partners. Originally the 3GPP scope was to introduce universally applicable third-generation (3G) mobile phone system specification that are based on evolved Global System for Mobile Communications (GSM) specifications under the scope of the International Mobile Telecommunications-2000 project of the International Telecommunication Union (ITU). 3GPP standardization encompasses Radio, Core Network and Service architecture. Later the scope of 3GPP was enlarged to encompass the development and maintenance of GSM including GSM evolved radio access technologies like General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE).

5.8 EE wimax

Worldwide Inter-operability for Microwave Access (Wimax) is a wireless communications standard. It is designed to provide data rates of 30 to 40 megabit-per-second. The updated version of 2011 was provision of 1 Gbit/s for fixed stations. WiMAX is one of the hottest broadband wireless technologies around today. It is expected that WiMAX systems will deliver broadband access services to residential and enterprise customers in an economical way. WiMAX would operate in a similar manner to WiFi but with a very higher speed and over greater distances, for much greater number of users [106]. WiMAX systems have the ability to over throw the limitations of traditional wired infrastructure limitations thus by providing the services with harsh physical terrain while considering wired infrastructure.

5.9 EE P2P

A peer-to-peer (P2P) network is one in which interconnected nodes share resources with each other without any restriction from the centralized administrator as compared to client-server model where clients request services and resources from centralized servers. Peer-to-peer (P2P) computing or networking is a distributed application architecture that partitions tasks or work loads between peers [7]. Peers are equally privileged, equipotent participants in the application. They are said to form a peer-to-peer network of nodes. Peers make a portion of their resources, such as processing power, disk storage or network bandwidth, directly available to other network participants, without the need for central coordination by servers or stable hosts. Peers are both suppliers and consumers of resources, in contrast to the traditional client-server model in which the consumption and supply of resources is divided. Emerging collaborative P2P systems are going beyond the era of peers, doing similar things while sharing resources, and are looking for diverse peers that can bring in unique resources and capabilities to a virtual community thereby empowering it to engage in greater tasks beyond those that can be accomplished by individual peers, yet that are beneficial to all the peers.

5.10 EE device to device communication

These days a global call for higher data rates in 3G and 4G cellular networks is being observed because of data voracious applications like multimedia down loading, video streaming, on-line gaming and large file sharing among users using cell phone. This forces cellular operators to adopt new technologies to satisfy customer demands of higher data rates that may also result in increase in their revenue as well. Realizing the importance of higher data rates, 3GPP has stressed the need to increase the bandwidth requirement of IMT- Advance system upto 100 MHz by incorporation of newer technological components. The IMT Advanced systems promises to improve local area services through efficient utilization of scarce radio resources.

D2D communication is a promising technology designed for Advance Long Term Evolution (LTE-A) where the users that are closely located to each other, can directly exchange information with out intervention of the Base Station (BS). Hence by doing so the power consumption of BS which has the major share in energy consumption of the overall system can be minimized and therefore, the notion of green communication can be facilitated. According to [107], different techniques are possible for controlled management of resources by the base station/eNodeB. Though, lot of work has been done through WLAN and WPAN technologies like Bluetooth and UWB that provide higher data rates, but also require manual peering and also, there is no control over interference as these services operate in license free ISM band. However, in D2D communication due to controlled assignment of radio resources by the Base Station in the licensed band, problems like manual peering and interference among users are alleviated to a greater extent. According to [108], benefits of D2D communication include; reduction in end to end latency due to reduced number of hops, higher bit rates due to proximity of users, low power consumption thereby enhancing battery life of users; Wireless cellular networks are evolving towards the advance and intelligent structures to achieve better network capacity, coverage and QoS.

5.11 EE 5G networks

As the demands for capacity is increasing dramatically due to which the deployment of 4G system has already taken momentum. Therefore, the people related to research and development has taken the initiative of exploring next generation wireless technology. This 5G system will meet the capacity demands of the mobile internet up till year 2020. For which different organizations like 5GNOW and METIS under the umbrella of European Telecommunication Standards Institute's (ETSI's) Framework 7, 5G Research Center Uk, Third Generation Partnership Project (3GPP) and IMT-2020 China have already started the study over the spectrum characteristics and users demands etc [109].

6 Conclusion and future research directions

The efforts behind this research is to review the resource management techniques through which the EE of the wireless networks can be increased. Our goal is to pinpoint and understand the problems associated with EE in wireless communication systems. Adverse effects associated with poor EE are the increased hazardous carbon emissions along with the increased energy budget necessitated the green communication in wireless systems. For that matter a survey has been carried out indicating current and future research directions for attaining green communication. Energy efficient optimization framework is explored showing the types of optimization problems and the constraints mostly associated with EE communication. In the same context of improvement of overall wireless systems EE, the design of green networks that includes green wireless network architecture is also discussed for the purpose of understanding. These architectures cover the radio component, network operation and topology, and incorporation of alternate energy sources while stepping towards green communication. Radio resource management plays a pivotal role in increasing the EE of the wireless system. Therefore radio resource management has been explored categorically in homogenous, heterogenous and cooperative networks. Technologies and standards adopted for attaining green communication has been explored categorically and a concise literature survey is carried out for enhancement of energy efficiency of the wireless systems. This survey indicates that there are still many problems associated in attaining green radio resource management that need to be explored. Due to the vast background of this research it is concluded that more extensive and persistent efforts are required with the goal of transforming SE paradigm with more EE centric framework. The future research directions that have been identified in attaining green communication are shown in Table 1. In this regard, the state of the art energy efficient MIMO and OFDMA schemes, as well as the cross-layer optimization designs must be taken into account. The main findings include:

1. Energy efficiency of OFDMA systems can be increased by jointly allocating resources using spatial diversity of the MIMO schemes. This joint allocation increases the overall system complexity for which new algorithms need to be developed for achieving a better tradeoff between the system complexity and performance.

2. The multi-cell scenarios in OFDMA and MIMO systems can be further explored for enhancing the energy efficiency. Although, substantial amount of work has already been done but the performance of EE in presence of inter-cell interference in MIMO and OFDMA multi-cell scenario, is still unclear that needs to be explored.

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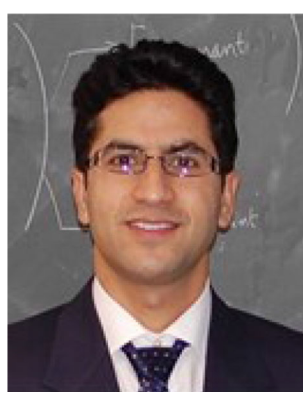

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