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ICT and renewable energy: a way forward to the next generation telecom base stations

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Abstract The tremendous growth in technology is also causing global warming due to harmful greenhouse gas emissions. The Information and Communication Technology (ICT) sector is one of the fastest growing, having the greatest impact on almost every other technology. Energy efficiency and reduction in global warming is now a desire and realization by all key players associated with this technology. Not only there is scope for energy efficiency in ICTs itself but it can also help other sectors in becoming smart i.e., energy efficient. Smart buildings, smart motors, smart logistics and smart grids are being realized with the incorporation of information and communication technologies. The ICT industry is equally aware of the potential benefits of renewable energy sources (RES) in making the future systems greener and sustainable. This is quite evident from the research that is going on towards sustainable ICT solutions, as reviewed in this paper. Not only renewable energy is applicable to large scale applications like telecom base stations (BS), it is also applicable to small and medium scale systems and devices like computer peripherals and electric vehicles. In order to explore the evident potential of RES, all aspects of renewable energy are being addressed by the researchers. These aspects can broadly be categorized as generation, distribution, management and most significantly application of renewable energy. This paper takes a broader look at both aspects in which ICTs are making our world eco-sustainable i.e., making other technologies smarter and incorporating renewable energy sources wherever possible.

Keywords Green ICT · Renewable energy · Energy efficiency · Eco-sustainability

1 Introduction

In the last century mankind has seen unprecedented growth in technology as compered to the previous centuries. Within a century we have taken the sky, landed on the moon and sent spacecrafts deep into the solar system. From simple messaging across the Atlantic, we now send pictures and videos across the globe and beyond in multitudes. There is not a single aspect of our lives that has not seen an exponential advancement in technology. Whether it is medicine or transportation or construction or aerospace, everything is touched by technology. This unprecedented growth in technology has been made possible partly by the easy and vast availability of electrical energy. The advent of electricity has ushered an era of growth based on technologies that run on electric power [1]. The electricity dependent systems consume a huge amount of energy overall for technologies dependent on these systems. The computing power in today's smart phones is more than the computing power of the computers that sent man to the moon [2]. And whereas, it is increasing day by day, the system size is reducing and getting cheaper—driven by Moore's law till late. The result is an exponential growth of technology in all sectors.

The demand for energy is exponentially increasing as technology is infused into every aspect of our lives. Global demand for energy is expected to rise by 37 % from 2013 to 2035, or by an average of 1.4 % per year [3]. Presently, three main fossil fuels, namely oil, natural gas and coal account for

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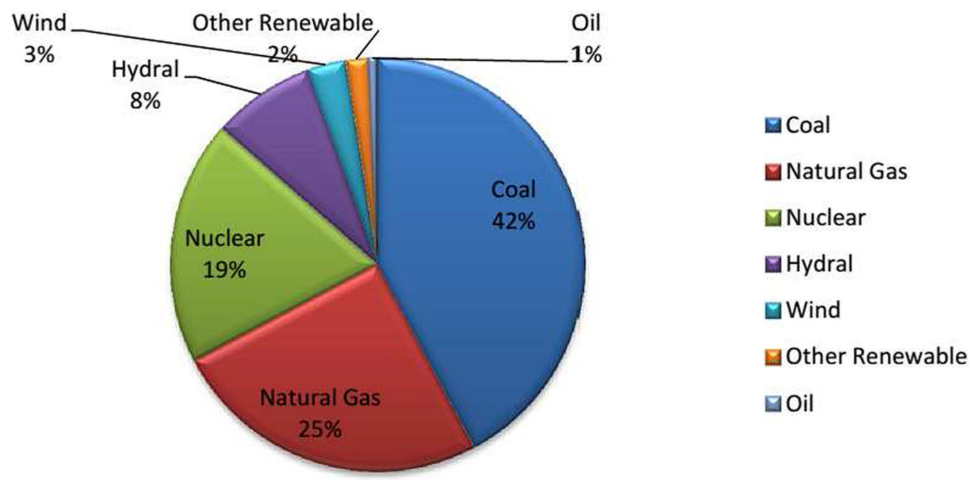

Fig. 1 Electricity generation from different fuel sources world wide (source www.iea.org/)

almost 80 % of the energy produced, to run the show [4]. The rest 20 % is made of hydro, nuclear and renewable sources. Since most of the technology is dependent on electricity, its generation is the main concern/requirement for technology sectors to sustain growth. As stated, the main sources of energy consumed to generate electricity are the fossil fuels. According to the world energy statistics given by International Energy Agency (IEA) www.iea.org/publications/freepublications/publication/Electricitytrends see here, electrical energy is being produced from fossil fuels, hydro, nuclear and renewable sources in the ratios as shown in Fig. 1. Renewables amount to mere 5 % of electricity generation, whereas, coal is the most common fuel for the world's electricity plants accounting for more than 40 % of world's electricity generation. In 2005, global electricity consumption averaged 2 TW. The energy rate used to generate 2 TW of electricity is approximately 5 TW, as the efficiency of a typical existing power plant is around 38 % [5]. The new generation of gas-fired plants reaches a substantially higher efficiency of 55 %. Three recent reports released by International Energy Agency (IEA), Energy Information Administration (EIA) of US and British Petroleum (BP), present a detailed review on global energy outlook. All three reports estimate that the global consumption of oil/equivalents will almost double from 9 billion toe (tons of oil equivalents) in year 2000 to around 18 billion toe in 2035 [6]. Although authors in [7] conclude that the electricity-growth nexus is highly sensitive to a country's region, income levels, urbanization rates and supply risks.

The energy produced is being consumed by all sectors of technology and all types of industries that include aerospace industry, construction industry, transportation industry, farming sector, mining sector, ICT sector etc . The consumption of energy world wide is increasing at an alarming rate as indicated in the aforesaid reports. According to US Department of Energy's "International Energy Outlook 2007", industrial users (agriculture, mining, manufacturing, and construction) consume about 37 % of the total 15 TW of energy consumed [8]. Personal and commercial transportation consumes 20 %; residential heating, lighting, and appliances use 11 %; and commercial uses (lighting, heating and cooling of commercial buildings, and provision of water and sewer services) amount to 5 % of the total. The other 27 % of the world's energy is lost in energy transmission and generation. Thus, mankind is paying a heavy price for modern technologies in terms of adverse climate change as well as rising financial burden. Without energy efficiency improvements, the OECD (Organisation for Economic Cooperation and Development) nations would have used approximately 49 % more energy than was actually consumed as of 1998 [9]. Moreover, these supplies are not perpetual and are bound to end one day.

As a result of this growth in technology and consequential increase in energy consumption, there is an adverse effect on the climate due to the greenhouse gas (GHG) emissions [10]. The Intergovernmental Panel on Climate Change (IPCC) states that warming of the climate system is unequivocal, and is mainly due to an increase in GHG emissions from human activities. According to the Panel, warming of the climate will probably lead to extreme weather events becoming more frequent and unpredictable, and that limiting climate change will require substantial and sustained reductions of GHG emissions [11]. The negative effects of global warming have been established beyond doubt and the world is at a general consensus that we need to cut down on GHG emissions and move towards a green and sustainable future. Consequently, energy sustainability and energy efficiency are the prime goals for which research is underway in a vast areas of science. The aim is to carve out a future where technology becomes as energy efficient as possible and the energy requirements become sustainable with minimal adverse effects on climate change [12].

The above stated aim is being pursued by adopting a two pronged approach in handling energy efficiency and sustainability, which may be broadly categorized as follows:-

- Innovate SMART systems and processes in every sector, as far as possible, to make systems energy efficient.
- Incorporate the usage of renewable energy (RE), as much as possible, to make energy requirements sustainable and green.

Not surprisingly, ICT has a role to play in both i.e., making current systems/infrastructures smarter and energy efficient, and making renewable energy viable for use at macro and micro level [13,14]. The rest of the paper is organized as follows. Section 2 discusses the SMART initiatives that are possible through ICT in achieving energy efficiency in all technology sectors including ICT itself. Section 3 discusses the issues in incorporating renewable energy and sustaining them. In Sect. 4 we discuss the case of incorporating renewable energy sources on a cellular base station. The paper is concluded in Sect. 5.

2 Getting smarter through ICT

Like other technology sectors ICT sector also has a significant contribution towards global warming through CO_2 emissions [15]. There is direct contribution from ICT sector itself and indirect contribution through other sectors where ICT is employed to support their businesses [16]. In ICT, the energy consumption mainly occurs at the data centers and the wireless base stations (BS). According to Gartner report of 2007, ICTs are contributing two percent towards global warming, which seems quite less as compared to some other sectors such as construction and transportation [17]. However, this technology is the fastest growing and holds the key to reducing energy consumption across all other technology sectors. The advance information and communication technologies act as the enabling technologies for other sectors as enumerated in subsequent paragraphs. Thus ICT can not only become smart itself, but also help other sectors in becoming smarter and thus energy efficient [18]. A review of Internet shows that a number of consortia, organizations and foundations, both in public and private sector, are working around the world- notably in Europe and Northern America- that aim not only to move information and communication technology towards a greener path, but also help other technologies in becoming greener. In developing countries also there are plenty of opportunities for development as highlighted by authors in [19].

2.1 Reducing ICTs own energy consumption

The Information and Communication Technology (ICT) sector, can be sub divided into three sub-sectors, namely telecommunication and devices sector, PCs,printers and peripherals' sector and the data centers. Over the past few decades, all three of these sectors have seen a continuous increase in usage and consequently in their energy consumption. This increase has been the result of number of factors, such as, widespread use of computers in homes, offices and businesses, exponential growth in networks and mobile connections, and vast amount of data storage and high data throughput. The combined carbon footprint of these sub-sectors was estimated at 0.83Gt of CO_2e (carbon dioxide equivalents) emissions in 2007 which is estimated to increase to 1.43Gt of emissions by 2020 [20]. Figure 2 shows the percentage wise share of emissions of the three sectors, which is 31 % for telecom, 40 % for PCs and peripherals and some 23 % by the data centers [21].

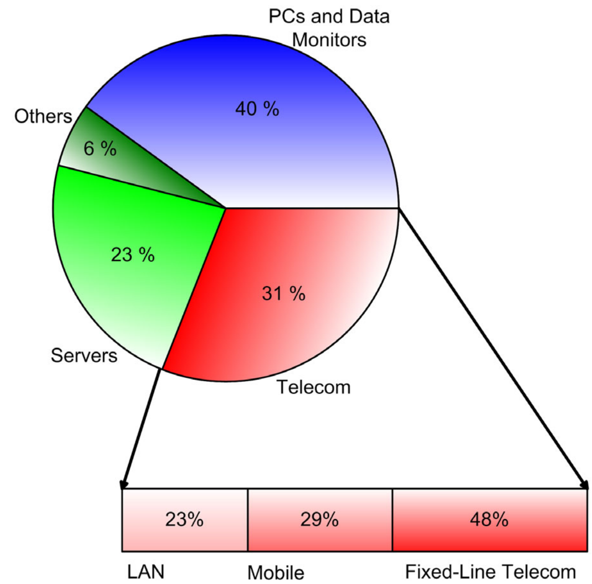

Fig. 2 Distribution of Green House Gasses (GHGs) amongst different elements of ICT sector

One way to make information and communication technologies energy efficient is by making them SMART. Google has built a data center on Oregon's Columbia river to tap hydroelectric power while Microsoft did the same in Washington for the same reason. Financial services company HSBC is building a data center near Niagara Falls. In US, one of their state (Wyoming) is trying to lure data centers with the promise of cheap power from coal-fired plants [22]. The ICT sector can make significant reduction in its carbon footprint by adopting SMART measures that conserve energy and reduce its carbon footprint. The SMART way for the sector has been outlined by [20] as follows:-

- Standardization of energy measurement techniques. The first requirement towards energy conservation is to know how much energy is being consumed. For this we need energy measurement techniques that are not only effective but also uniform. All devices and systems should have a common yard stick for measuring energy to ensure correct data on consumption.

- **M**onitoring energy consumption across the board. monitoring through sensors and meters should be ensured on each and every segment of technology so that a complete and comprehensive picture is obtained.
- **A**ccounting for energy at every step. Energy is not only consumed at the server or the end equipment but should be accounted for at every node where it is being dissipated, however little it may be.
- **R**ethinking and researching innovation to reduce ICT's emissions across devices and service. Constant innovation has resulted in smaller and lighter components resulting in reduction in energy consumption. This process needs to continue through research, to explore all possible ways and means by which energy efficiency can be attained.
- **T**ransformation of ICT sector into an exemplar of low carbon technology. ICT sector has the capability to demonstrate highly efficient systems. It can not only transform itself into a green technology but also lead the path for others to follow.

2.2 ICT's enabling support to other sectors

Although ICT sectors own emissions will rise as global demand for products and services increases, these are estimated to be five times less than the emissions that can be reduced through the enabling effect of ICT sector. The SMART2020 report [20], states that ICTs have the capability to reduce global GHG emissions by 7.8 Gt by 2020, from an estimated total of 51.9 Gt of total CO_2e emissions from all sectors; an amount five times larger than its own projected carbon footprint of 1.43 Gt of CO_2e . Since ICT operates on the cutting edge of technology, any breakthrough here is bound to benefit other sectors also. For example, smart grids are considered to be a key technology in reducing energy losses and increasing energy efficiency. Smart grids heavily rely on ICT in terms of communication technologies required to make the electrical grid interconnected and intelligent. Similarly smart homes, smart buildings and smart logistics are also going to benefit directly and indirectly from advancements made in the Information and Communication Technologies as discussed below.

The information and communication technology's enabling action in making others smart is largely due to its ubiquitous nature, such as extending ICT protocols and capabilities into other sectors [23]. ICTs have become part and parcel of most other technologies because they provide them with computational power and intelligence to perform better and act smarter. It can not only provide products to support collection and analysis but also help to develop new techniques for replacing high carbon activities with low carbon activities. ICT can help in optimization of systems and processes for energy efficiency [24]. It can also help in the innovation processes of the companies by simulating different changes in systems and company strategies. Last but not the least, it can help promote cooperation between sectors in implementing smart energy management approaches.

Next, we look at some specific examples of ways and means to have smart homes, smart buildings, smart logistics, smart motors and smart grids. These ways and means can be categorized into three main areas, namely software, management systems and devices. Software and computers can be used for variety of applications that can help in energy efficiency, such as:

- Real time processing of data
- Energy accounting in grids and buildings
- Design and modeling software for systems/infrastructures
- Load analysis software for buildings and plants
- Load analysis software for machines and systems
- Smart billing/IP based billing
- Real time route optimization software
- Simulation of system performance
- On-line/ off-line power fault analysis software
- Protocols for interoperability between systems
- Demand response software for load management

A number of ICT products and devices are employed in every sector to help these in conserving energy, such as:-

- Data recorders
- Data loggers
- RFID tags for asset tracking
- Chargers and controllers
- SMART meters
- Sensors for remote measurement
- Chips and controllers for monitoring
- Interconnectivity between systems
- Alarm systems
- Contingency alert systems

The third aspect through which ICT can bring about energy efficiency into other technology sectors is through its management and information systems, such as:-

- Maintenance, repair and operations (MRO) platforms
- Operation support systems for energy management
- CO_2 emissions tracking platforms
- Internal and external communications systems
- Automation systems for buildings, plants, machines and transport
- Work-flow management systems
- Vehicle/fleet tracking and global positioning systems

2.3 ICT sector's green initiatives

Since the launch of 'Energy Star' programme in 1992 by US Environmental Protection Agency, awareness on energy efficiency and climate change has come a long way. A number of projects and initiatives have been taken up by public and private organizations to make ICT green. The international federation for green ICT[1] is regulating green technology standards based professional programs called Green ICT Standard. Others include European 'EARTH'(Energy Aware Radio and neTwork tecHnologies) project and 'Green ICT' project[2], the international 'Green Touch' consortium[3], and UK's 'Green Radio' project etc. Another such body, Global e-Sustainability Initiative (GeSI)[4], in its report cited earlier [20], estimates that by 2020 the ICTs will be responsible for cutting down GHG emissions of other sectors five times more than its own GHG emissions. Similarly, the goal of research under 'Green Radio'[5] is to secure 100x reduction in energy requirements for delivery of high data rate services, thereby reducing CO_2 emissions and OPEX(OPerational EXpenditure) costs whilst enabling new services. According to 'Green Touch'[6], a Bell Labs initiative, about 3 % of world wide energy is consumed by ICT, which causes about 2 % of the world wide CO_2 emissions. The Green Touch project aims to create 1000-fold improvement in energy efficiency by transforming ICT infrastructure globally by utilizing innovative technologies. Similarly, the Green Grid association[7] is another open industry consortium of some 200 member entities globally, that works to improve ICT resource efficiency around the world. In all such initiatives the aim is to have eco-sustainable solutions in ICT sector. However, a survey of over 90 government and industry initiatives on green ICT that has been carried out by OECD (Organisation for Economic Cooperation and Development) concludes in their report that most of these initiatives concentrate on greening ICT itself, rather than enabling other technologies in tackling global warming.

3 Getting greener through ICT

The authors in [12] challenge the view that improving energy efficiency will lead to a reduction in energy consumption, hence reducing CO_2 emissions. It argues that improving energy efficiency lowers the implicit price of energy and hence make its use more affordable, thus leading to greater use an effect termed the rebound effect. The paper argues that a more effective CO_2 policy is to concentrate on shifting to non-fossil fuels, like renewable. This assessment may be debatable, but there is no denying the fact that all technology sectors heavily rely on the use of electricity, thus an obvious way to reduce carbon footprint due to electricity consumption is to use renewable energy as far as possible. These sectors should procure energy from green sources as much as possible, and introduce renewable sources into their systems and products. A case in point is the cellular base station of the ICT sector, which can be converted on green energy by installing renewable energy sources on the sites (Sect. 4).

In using renewable energy, the first step is to harvest the energy embedded in nature and store it for further use. The next step is to distribute it among the consumers and users by efficient means. Then comes the incorporation into systems for various applications. And lastly, managing this energy for efficient use and sustainable growth. These four aspects are surveyed and discussed in the subsequent four subsections of this paper. The overall desired impact is to have working models that are greener, have a lower carbon footprint and are diffused into the industry as well as society at the required scale [25].

3.1 Harvesting and storage

Harvesting and storing the energy generated through renewable sources like solar and wind energy is paramount for its subsequent utility [26]. Other renewable sources include hydral, ocean and biomass but are not as widely applied as PV panels and wind turbines. The energy harvested from solar and wind is unstable and unpredictable by nature. Due to this the following aspects are very important when harvesting such energy. First, maximum amount of energy should be harvested as possible, and also a system should be available for efficient storage for regulated reuse. The max efficiency of wind turbine is 59 %, known as the Betz limit, meaning that 59 % of wind kinetic energy can be converted to electrical energy, at max. Whereas, a photovoltaic cell can only be 33 % efficient as per Shockely–Queisser limit (commercial PV panels are about 15 % efficient). This explains the large number of solar panels and large scale wind turbines required to produce sufficient amount of electrical energy.

As technology related to RES like PV cells and wind turbine matures, various designs and models are emerging for specific applications and deployments. Harvesting from other ambient energy sources like RF and thermal is also increasingly studied as advancements are made in microelectronics and Micro Electro-Mechanical Systems (MEMS). In this regards state-of-the-art in energy harvesting from vibrations, thermal and RF energy is described in detail in [27].

[1] www.ifgict.org
[2] http://www.green-ict.com/
[3] www.greentouch.org
[4] http://gesi.org/
[5] www.mobilevce.com/green-radio
[6] www.greentouch.org
[7] www.thegreengrid.org

The harvesting of renewable energy for ICT applications is itself subject of much research as literature suggests and following examples illustrate. In this regards different ideas are explored by the researchers for general or specific applications. For example, in case of wind turbines, Garca et al. [28], have carried out a review of the state-of-the-art in the CM (condition monitoring) of wind turbines, describing different maintenance strategies, CM techniques and methods. Eriksson et al. have proposed the design of a generator for a vertical axis wind turbine [29]. Hameed et al. have researched practical aspects of a condition monitoring system for a wind turbine with emphasis on its design, system architecture, testing and installation [29]. A wind farm layout optimization using particle filtering approach has been carried out by authors in [30]. In a particular application of generating electricity for sustainable development of rural and remote communities in Kiribati, Mala et al. [31], have studied installation of solar photovoltaic (PV) on atolls. Wireless power transfer (WPT) is a new dimension in energy sharing and energy harvesting under latest research. Work done to examine the role of pilot projects in the development and acceptance of WPT as an enabling technology for space solar power systems is presented in [32]. WPT is also being explored as a viable option in cellular base stations and other wireless networks like WSNs [33].

Storage of the electrical energy is as critical as harvesting because large scale storage is a serious impediment in use of renewable energy. For small and medium scale applications like solar lights and solar powered homes, respectively, rechargeable batteries/ battery banks are used that have their own useful life. Particularly for ICT sector, harvesting energy is very lucrative for applications heavily relying on battery power like medical implants and radio hand-sets. Energy storage being the lynch pin in renewable energy utilization, is vigorously researched as demonstrated by Parameshwaran et al., who have carried out a detailed review of sustainable thermal energy storage technologies for buildings [34]. ICT industry has taken up the challenge of producing high density low cost batteries that are critical to renewable energy applications as well as other applications. Energy storage for community and mass level utility is discussed in detail in [26], which describes five innovative ways to store energy for large scale reuse. These are: Storage in water reservoir, storage using Fly wheels, storage in under ground caves, use of cheaper large capacity batteries and employing smart grids.

3.2 Distribution of renewable energy

Distribution of renewable energy generated through various sources is as important as its generation and utilization, and requires equal attention. That is why research is being directed towards infrastructures and policies of distribution networks. Smart grids are the key to energy distribution and thus focus of special interest by the researchers. There is study to integrate the present grids with right communication infrastructure to make them smart or to develop new grid designs that have communication technology fused into them [35]. A concept closely associated with energy generation and smart grid is the concept of distributed generation (DG) but lot of terminologies and definitions exist in the industry, which have been amply explored in [36]. It basically means generation of electric power within distributive networks on the customer side as shown in Fig. 3. DG is often classified according to the capacity of the electricity generation plant, which typically ranges from tens of kilo Watts to few mega Watts of electricity. Other characteristic of DG are defined according to its purpose, the location, the technology, the mode of operation, and the power delivery area [37]. The technologies that can be used for DG can broadly be categorized into renewable distributed generation, modular distributed generation and combined heat and power (CHP) distributed generation.

A smart grid can be defined as ICT-enabled distributed generation of electricity. ICT can provide the required intelligence and computing power to the distribution system to make it efficient and controllable. An overview of the essentials of the progressive smart grid paradigm and integration of different communication technologies for legacy power system has been presented in [38]. A study of communication infrastructures and network architecture for the smart grid has been undertaken by the researchers in [35], and [39] respectively, while the objective of [40] is to design decentralized controls and communications for autonomous distribution networks in Smart Grid. In [41], an overview of demand management with a particular focus on the necessary enabling wireless technologies is presented. Smart grid employing renewable energy is an extended concept also under research that aims to make the grid green. A novel concept for a renewable network within municipal energy systems has been put forward by researchers in [42]. Similarly a special case for the design and implementation of a measurement system for grid-connected marine substation has been carried out in [43].

3.3 Incorporation into systems and networks

3.3.1 Applications in devices and systems

The ready availability of RES like solar and wind energy is attracting researchers to integrate these into different ICT devices and systems as shown in Fig. 6. The application can be as small as a solar powered wireless mouse undertaken as a case study by N.H. Reich for the evaluation and optimization of industrial design processes of PV powered consumer systems [44]. Or it may be evaluation of ground energy storage assisted electric vehicle's DC fast charger for

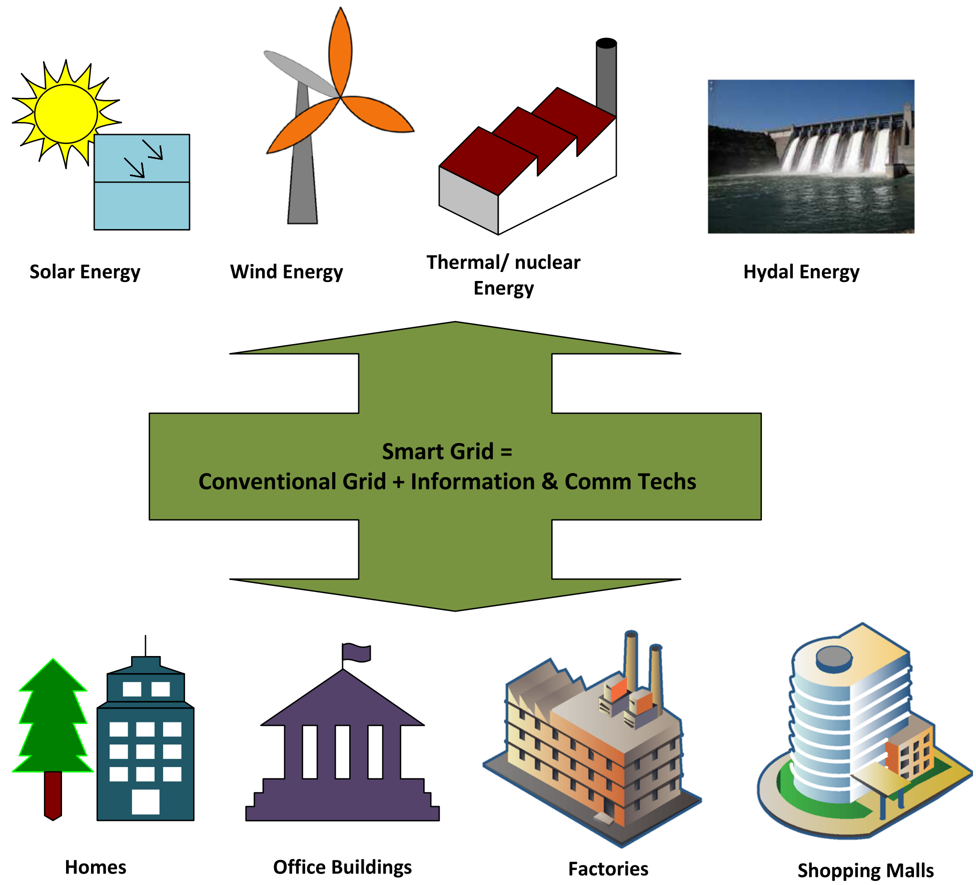

Fig. 3 A smart grid can be defined as ICT-enabled distributed generation of electricity with demand side management also

demand charge reduction and providing demand response, as proposed in [45]. As an example of applications for different systems, the development of wireless data acquisition system (WDAS) for weather station monitoring [46], and radio base station site solutions for the Ericsson SunSite, that are already in use [47], are of interest. In other applications, the communication systems are being subjected to performance analysis under renewable energy, such as the case of dynamic power allocation for maximizing throughput in energy-harvesting systems [48], and analyzing the theoretically achievable throughput of the secondary transmitter, carried out by authors in [49]. Authors of [50], have performed renewable hybrid stand-alone telecommunication power system modeling and analysis. Smart grid (SG) as a system is also under investigation as demonstrated by [37], which proposes a new conceptual design of an intelligent Supervisory Control and Data Acquisition (SCADA) system. Such systems regulate power in smart grids and smart homes connected to the SG. The futuristic smart homes, asshown in Fig. 4, may rely on power from sources other than utility, and may also have the capability to sell the surplus energy back to utility. The electronic devices in these smart homes are centrally controlled and utilized in such a way so that the overall energy bill is minimized while maximizing the

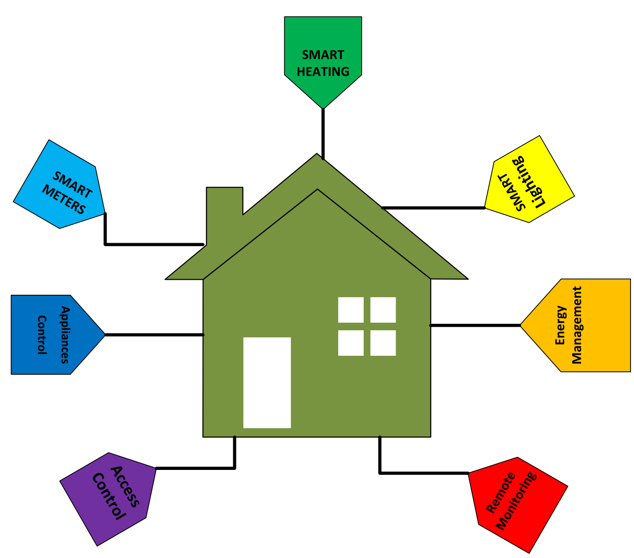

Fig. 4 The Futuristic Smart home will be equipped with Smart meters, heating, lighting and access control, appliances control systems, remote monitoring and overall energy management systems

use of alternate energy sources like PV cells, wind and bio-thermal etc. The energy management system of a smart home uses existing wiring for communication or may employ wireless technology (zigbee for example) to activate or deactivate devices [51–54].

3.3.2 Applications in networks

The communication networks of tomorrow are anticipated to make use of renewable energy sources (RES), mainly solar and wind power, to not only become environmentally viable but also to reduce operational costs in the long run.

Energy efficiency in networks by utilizing RES is explored by researchers for various wireless networks including wireless sensor networks (WSN), wireless mesh networks (WMN), multi-hop networks (AdHoc NW) and the like. For example [55], have proposed a framework of joint mobile energy replenishment and data gathering in wireless rechargeable sensor networks, whereas [56], have designed a dynamically reconfigurable hardware with a novel scheduling strategy in energy-harvesting sensor networks. Researchers in [57], develop a model to characterize the performance of multi-hop radio networks, while those in [58] have tried to determine an optimal spectrum sensing policy that maximizes the expected total throughput. In case of WMNs, Cai et al. [59], have proposed to maximize the energy sustainability of the WMN, and [60], have addressed the routing, rate control, and power allocation issues in energy renewable wireless mesh networks. Sustainability analysis and resource management for wireless mesh networks with renewable energy supplies has been carried out by researchers in [61]. Zhang et al. [62], discuss ways in improving communication energy efficiency in wireless networks powered by renewable energy sources.

In other works pertaining to networks, authors in [63], propose a novel design of climate change monitoring system based on ubiquitous WSNs with solar power supply. In [64], green monitoring using a wide area radio network/or sensor (WARNS) communication has been studied. Researchers in [65], have described integrated V2G, G2V, and RES coordination over a converged Fiber-Wireless broadband access network. Maximizing a-lifetime of wireless sensor networks with solar energy sources has been researched by Abu-Baker et al. [66]. Optimal adaptive modulation for QoS constrained wireless networks with renewable energy sources has also been studied [67]. Sarkar et al. have addressed optimal routing and scheduling in multihop wireless renewable energy networks [68]. Raul Morais have proposed a solar data acquisition wireless network for agriculture applications [69] and a wireless network of autonomous environmental sensors is given in [70].

3.4 Management of renewable energy

Renewable energy sources are inherently unstable and unpredictable yet sustainable in the long run. These factors introduce new challenges for network planning and resource management. Adaptive resource management is required for wireless networks that are powered by sustainable energy sources. The objective is to address the unreliability of the energy supply and maximize the energy sustainability of the network. Factors to be considered for management include energy sensing mechanism, demand side management and energy storage management.

3.4.1 Energy sensing mechanism

Employing mechanism such as smart metering, the energy can be sensed at different nodes in a network. The distributed generation in the network is also monitored in real time to asses the overall energy available. Efficient processing is required at control centers and some nodes to channelize the energy available from the renewable sources [71].

3.4.2 Demand side management

The end consuming the energy participates in management of energy resources by real time monitoring and analysis of its load. Accordingly response is generated which is communicated to the source through bidirectional coordination. Demand side management requires monitoring of specific performance parameters, such as potential demand and local backup supply [72].

3.4.3 Energy storage management

Due to its unstable characteristic, the renewable energy is stored prior to its regulated consumption. Batteries and battery banks are the most common form of energy storing devices (ESDs) in use with RES. Their management involves regulating their charging/ discharging, protection from overload or underload, energy flow in conjunction with other sources etc. Such management requires proper monitoring of its state of health and key parameters like voltage, current and temperature [73]. Authors in [74], have developed an energy management system (EMS) to control power flow among system components, and battery charging and discharging processes to operate each battery in a way that minimizes the ageing for all batteries; simulated in Matlab/Simulink for a time frame of twenty years.

Apart from focusing on the purely technical aspects of RES, researchers are also discussing ways to make RES economically viable and practically reachable. The aim is to integrate renewable energy into society as a long term prospect. It is one thing to have the system working on paper and quite another to have it practically implemented outside the scientific community. Thus it is as important to make RE viable so that it is successfully adopted by the society. For example in [75], authors discuss identification and assessment of sustainable energy investments in the framework of EUGCC to make it marketable. In [76], mechanisms for adopting a private sector driven business model approach for successful diffusion of Sustainable Energy Technologies (SETs) is discussed in detail. Likewise, Mani et al. have put forth different ideas to accelerate adoption of renewable energy sources by consumer communities in India [77]. In [78], the authors have carried out a study on the potential utilization of renewable energy sources in Turkey. Similarly, as an example of practicality, researchers in [79] have addressed the issue of sizing and optimization of maintenance visits of a hybrid photovoltaic-hydrogen stand-alone facility using evolutionary algorithms.The bottom line is that technologies associated with renewable energy have to merge into the market horizontally across different spheres of life, as well vertically across the hierarchy of market tiers, so as to become as common place as other technologies like vehicles, mobile phones, air conditioners etc.

4 The case for green base station

Improving energy efficiency in cellular networks involves energy reduction of all elements in cellular networks, such as mobile core network elements, mobile switching centers, base stations, mobile back haul networks, and mobile terminals [80,81]. Amongst the mentioned elements, the base station is the most energy hungry component, consuming approximately 60 % of the total energy required by cellular network [82], as depicted in Fig. 5. For the BS of a 3G and LTE network this ratio increases to 75–80 % [83]. Thus, BSs have become the prime focus of research for energy efficiency as far as cellular communication is concerned. One of the most revealing findings of this research is that on the average, the vast majority of a networks resources are idle.

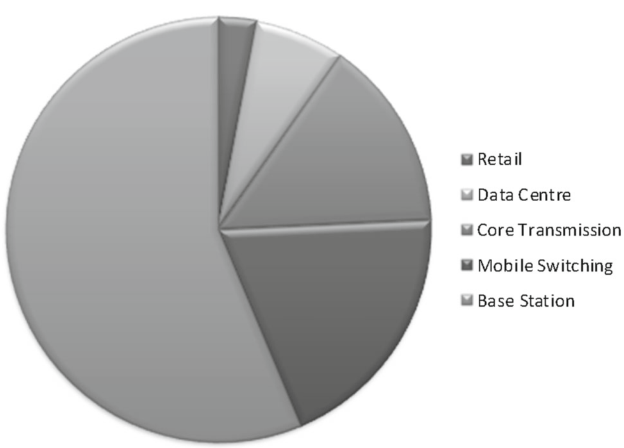

Fig. 5 Relative power consumption of cellular elements of mobile communication

Moreover, the energy efficiency of a eNodeb is particularly low at low traffic load. This shows that a networks energy efficiency can be greatly increased by manging a network's operation.

A typical base station consists of different sub-systems like baseband (BB) processors, transceiver (TRX) (comprising power amplifier (PA), RF transmitter and receiver), feeder cable and antennas, main supply, DC–DC converters, and cooling units [84], all of which consume energy and can be a target for energy efficiency. In this regard, use of renewable energy, in conjunction with utility and generator power, can provide a cost effective alternate, especially for off-grid or stand alone base stations. There are different techniques and methodologies under study to make a BS energy efficient. There are many ways of achieving energy efficiency in a BS, such as improving efficiency of the hardware, improving the network protocols, improving the system architecture and network deployment tailored to traffic requirements, or using low-power micro base stations compared to today's high-power macro base station schemes [85] etc. The techniques involving network management include energy cooperation between BSs, on/off switching of BSs, cell zooming, cell sleeping and incorporation of renewable energy sources.

Powering cellular BSs with renewable energy sources (RES) is a viable and feasible option, as demonstrated by the large number of literature available on the subject. The RES of choice that have been mostly used to harvest the energy are the solar (PV panels) and wind (wind turbines) energies. Often the hybrid of the two is modeled for generating green energy at a BS. Not only is RE a viable option for stand-alone BS but also for the BSs that are connected to the grid (conventional or smart). Different aspects of energy management have been studied with an aim to maximize the use of green energy and minimize the dependence on grid energy. Whereas it gives incentives to the network provider of reduced energy bill, it also contributes towards the larger goal of industry to reduce its CO_2 footprint (Fig. 6).

4.1 Resource management in green base station

The initial interest in green wireless communication started with modeling a single BS with renewable energy sources (RES). The main objective is the optimization of power management of the BS or simply its energy/radio resource management [86]. The use of renewable energy is intended to reduce the BS operating expenditures cost as well as make use of the clean energy. There can be a number of objectives towards achieving the stated goal: such as optimization of battery sizing, balancing power from utility and RES, overcoming the uncertainties in energy generation, its storage and consumption etc. In a green BS, both the supply of energy from RES and the user traffic load are dynamic in nature. Thus optimizing the use of green energy is a characteristic of

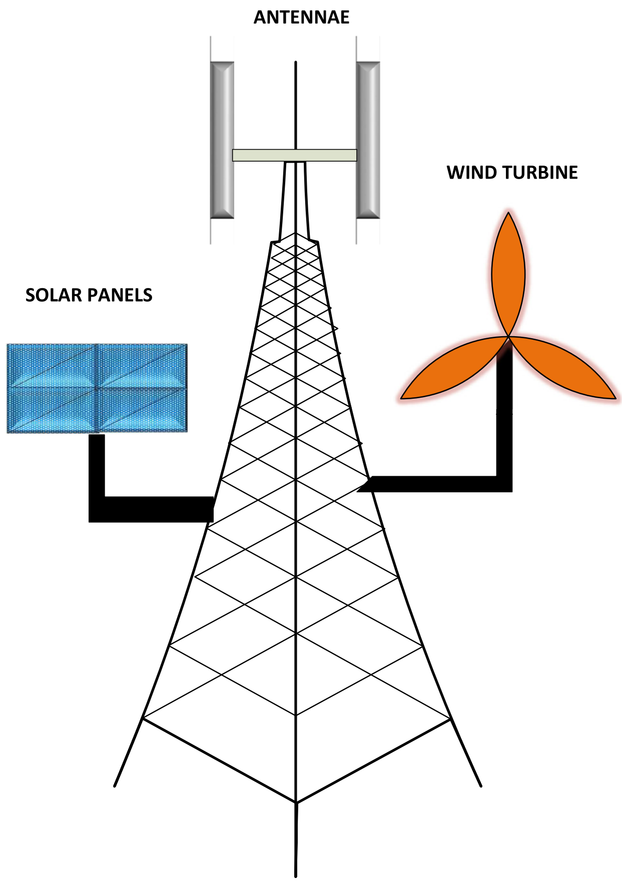

Fig. 6 Incorporation of renewable energy (solar and wind) into a cellular base station for electricity generation is quite feasible

energy arrival and energy consumption in present and future stages. Also balancing various energy sources namely, solar, wind, grid, generator in a BS is an optimization problem that has been addressed in many ways. The two main aspects of such optimization are:

- Estimation of current energy arrival and consumption, as well as future energy arrival and consumption.
- Maximization of green energy utilization at each stage, while meeting the network's QoS requirement.

Thus, modeling a BS with RES is a function of balancing energy sources, efficient energy storage and optimum energy consumption. Some models target a particular technology with pre-defined specifications such as capacity, load, bandwidth etc. Others model the uncertain nature of renewable energy for its best utilization, configuring certain elements of a BS for energy resource management. The infrastructure of a BS is particularly suited for installing small scale wind turbines and PV panels. Thus BSs have mostly been configured for either PV panels or wind turbines or hybrid of the two [87]. For example, a wind-powered tower for base station of cellular networks has been developed by Ericsson [88]. Similarly, Nokia Siemens Networks has also developed a hybrid (Solar and Wind powered) green BS to sustain off-grid operations. China mobile has erected a fuel cell based off-grid BS at Langfang, powered only by RES, with Electropower Systems Ltd providing the enabling technologies [89]. The site is a 3G/4G dual-mode base station. At the site the annual average solar irradiance is about 4.32 kWh/day/m^2, wind speed is less than 4 m/s and the base station power absorption is set to 1kW. The system comprises five sub-systems, an integrated fuel cell system, a hydrogen generator with hydrogen cylinders for storage, wind turbine, solar panels and an energy management unit. The model is claimed as 100 % green, powered only by solar and wind, giving zero CO_2 emissions.

With multiple power sources (grid, generator, solar, wind, batteries) available in green BSs, optimal management of these resources becomes a challenge that has been taken up by researchers in variety of ways. For example, in [90], design specifications of an independent power supply system of a 3kW wind and solar hybrid has been presented for a 3G base station in China. Scholars in [91], have tried to model the most feasible configuration of a stand-alone hybrid energy system for GSM type mobile telephony base station in central India, with diesel generator as a backup. They conclude that considering the operating and maintenance cost, an autonomous site powered by wind-solar-hybrid system pays off in 2–4 years in a good sunny and windy location. On the other hand, in the problem of dimensioning the powering system for a typical LTE (long term evolution) BS, which solely relies on renewable energy sources, authors in [92], find that with current technology very large dimensions of solar panels are required for powering a BS in peak traffic hours. The subsequent sub-sections discuss the general scenarios of greening a BS with renewable energy.

Besides managing the generated/harvested energy for its optimum utility, it is equally important to define performance metrics and put in place a system for its measurement and analysis. For example, in order to capture the energy consumption perspective in analysis, in addition to the traditional quality performance metrics, the EARTH project defines 'power-per-unit area' and 'Energy-per-bit' as two important energy consumption metrics for a radio base station.

5 Conclusion

There is no other sector of technology with a wider impact on other technologies than the Information and Communication Technologies (ICT). In this paper we have seen that ICT has the ability to make systems smarter by various means, as well as greener by adopting renewable energy source [23]. ICT is not only widespread but also operates on the cutting edge of technology. The phenomenal growth in data rates available to users in all kinds of networks, both wired and wireless, has put tremendous demand on the ICT sector. While meeting these demands, ICT sector is also trying to reduce the energy bill and become green. The ICT sector is not only pursuing eco-sustainability and energy efficiency for itself but also helping in reducing electrical consumption by infusing technology into other sectors. The importance of renewable energy in reducing GHG emissions and providing cheap sustainable fuel is motivating ICT industry to integrate RES as much as possible. All aspects of renewable energy are being explored, which include its generation, distribution, management and application. The application of RES ranges from infrastructures like data centers and wireless base stations to devices like computer peripherals, to networks like wireless sensor networks and wireless mesh networks. The diverse approach of the researchers is a testimony to the fact that renewable energy has a definite future in ICT. The renewable energy powered cellular base station is the best example for a wide spread usage of green energy in the ICT sector.

A multidisciplinary R&D effort is required to bring energy efficiency into systems and devices especially networks. A collaboration between ICT and energy sector is required to have an integrated solution for ICT-enabled distributed generation system [93]. Reliance on renewable energy as much as possible, is required for which novel harvesting, storage and application efforts are required. Support for R&D actions cutting across disciplines and themes related to energy efficiency is required from government bodies, organizations and industry. Candidate topics are: Hardware components, monitoring and control, management of complex power systems, intelligent metering, and distributed generation etc. Energy efficient metrics and an energy evaluation framework is to be put in place for quantification of energy savings made through advancements. A holistic approach is required by the ICT sector to address all areas and all aspects of renewable energy, to produce viable solutions for practical implementation. Last but not the least, the knowledge on the subject needs to be spread widely to reach all parties, not just the researchers [94].

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