EMERGING GREEN TECHNOLOGIES

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About the Author

Matthew N. O. Sadiku received his B. Sc. degree in 1978 from Ahmadu Bello University, Zaria, Nigeria, and his M.Sc. and Ph.D. degrees from Tennessee Technological University, Cookeville, TN, in 1982 and 1984, respectively. From 1984 to 1988, he was assistant professor at the Florida Atlantic University, Boca Raton, FL, where he did graduate work in computer science. From 1988 to 2000, he was at Temple University, Philadelphia, PA, where he was made full professor. From 2000 to 2002, he was with Lucent/Avaya, Holmdel, NJ, as a system engineer and with Boeing Satellite Systems, Los Angeles, CA, as a senior scientist. He is presently professor of electrical and computer engineering at Prairie View A&M University, Prairie View, TX.

Dr. Sadiku has authored over 740 professional papers and over 80 books, including *Elements of Electromagnetics* (Oxford University Press, 7th ed., 2018), *Fundamentals of Electric Circuits* (McGraw-Hill, 7th ed., 2020, with C. Alexander), *Computational Electromagnetics with MATLAB* (CRC Press, 4th ed., 2019), and *Principles of Modern Communication Systems* (Cambridge University Press, 2017, with S. O. Agbo). In addition to the engineering books, he has authored books on Christianity, including *Secrets of Successful Marriages*, *How to Discover God's Will for Your Life*, and commentaries on all the books of the New Testament Bible. Some of his books have been translated into French, Korean, Chinese (and Chinese Long Form in Taiwan), Italian, Portuguese, and Spanish.

Dr. Sadiku was the recipient of the 2000 McGraw-Hill/Jacob Millman Award for his outstanding contributions in the field of electrical engineering. He also received the Regents Professor award for 2012–2013 from the Texas A&M University System. He is a registered professional engineer and a fellow of the Institute of Electrical and Electronics Engineers (IEEE) "for contributions to computational electromagnetics and engineering education." He was the IEEE Region 2 Student Activities Committee chairman and associate editor for IEEE Transactions on Education. Dr. Sadiku is also a member of the Association for Computing Machinery (ACM) and the American Society of Engineering Education (ASEE). His current research interests are in the areas of computational electromagnetics, computer networks, and engineering education. His works can be found in his autobiography, *My Life and Work* (Trafford Publishing, 2017) or on his website: www.matthew-sadiku.com. He currently resides with his wife Kikelomo in Hockley, Texas and can be reached via email at sadiku@ieee.org

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Green Communications and Networking

> Nothing can stop the man with the right mental attitude from achieving his goal; nothing on earth can help the man with the wrong mental attitude.
>
> **—Thomas Jefferson**

10.1 Introduction

The demand for ubiquitous wireless and Internet services has been on the rise for the past decades. This requires a considerable amount of energy, which is often underestimated.

Advances of mobile communication devices, such as smart phones, smart watches, and wearable healthcare devices, have moved us toward the era of smart society. Such devices have become an indispensable part in our daily life because they allow us to exchange information reliably from anywhere, any time. The global wireless data traffic shows no signs of slowing down [1]. However, there has been increase in the unnecessary energy consumption of the mobile communication devices. The increasing volume of transmitted data is sustained at the expense of a significant carbon footprint by the mobile communications industry. The implication of wireless network's environmental and social responsibility (energy efficiency and environmental impact) has been disregarded. Computers themselves risk becoming the "energy hogs" of the future, unless something is done. Powering over one billion personal computers, over four billion fixed and mobile telephones, and computer networks (including the Internet and wireless networks) around the world requires approximately 1.4 Petawatt-hr a year (7015140000000000000♠1.4×10^{15} W-hr) of electricity [2]. The projected carbon footprint of the mobile communications until 2020 is shown in Figure 10.1 [3].

In spite of the great progresses in optical communication and transmission, today's networks still rely heavily on electronic systems. The proliferation of information and communication technology (ICT) systems is causing energy consumption levels to reach distressing rates. There is a request of environmental protection from users and governments to reduce CO_2 emissions due to ICT. The United Nations Climate Change Conferences have been held yearly to evaluate the progress in dealing with climate change since 1995. Green communications and networking can introduce significant

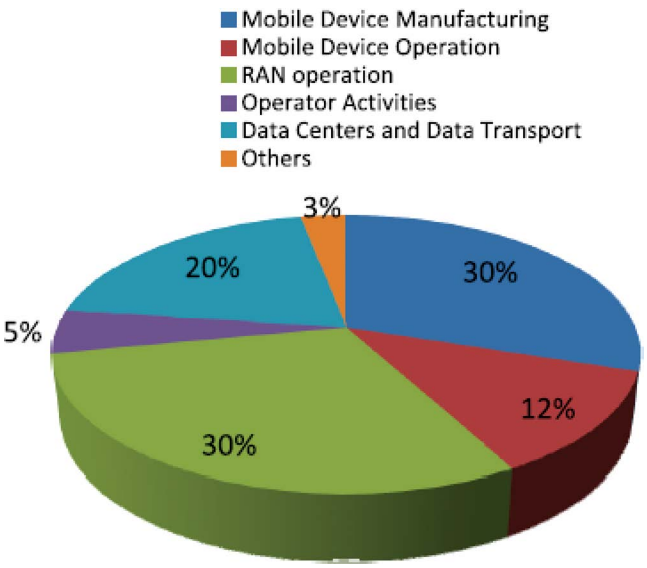

FIGURE 10.1
Carbon footprint of mobile communication (projected in 2020) [3].

reductions in energy consumption in the ICT industry. Green communication refers to communication that is sustainable, energy efficient, energy aware, and environmentally aware. It is also an environmental friendly communication. Green communication aims at balancing the resource usage and consequently saving the energy of entirely mobile and wireless networks. It is expected to address the growing cost, environmental impact, and CO_2 emission of telecommunication. With the rapid growth and evolution of communication and networking technologies, energy consumption is growing fast. Hence, green communication and networking are urgently needed [4].

This chapter provides an introduction to energy-efficient communications and networking, including wireless and wired networks. It begins by presenting some characteristics of green communication and green networking. Then, it discusses some common applications of green communication and networking. It addresses green metrics and some benefits of those technologies. The last section concludes the chapter.

10.2 Green Communications

ICT is one of the keys to a future low-carbon and sustainable society and the wireless communication networks constitute the largest share of the ICT. Communications technologies will be critical to achieve large-scale energy

savings. Reduction of the greenhouse gases (GHGs) caused by the telecommunication sector is known as greening of telecommunication, which has many facets. It can be classified broadly in terms of greening of telecommunication networks, green telecommunication equipment manufacture, atmosphere friendly design of telecommunication buildings, and safe telecommunication waste disposal [5].

The term "green" refers to recycling, purchasing, and using environment-friendly products. The key idea behind the concept of green communication is to find a way on how to encourage people to change their behavior in order to increase efficient use of communication systems. Green communication aims at reducing energy cost while still maintaining quality of service (QoS) in terms of coverage needs, capacity, and user needs.

Green communications require that all blocks in a communication system (the baseband, the transmitter, the receiver, and the signal modulation) are designed for optimum efficiency. The goal of green communication is to ensure that communication systems consume less energy and have a smaller carbon footprint. Strategies for achieving this include using renewable energy, biodiesel, and solar and fuel-powered cell sites, and installing fuel catalysts and cooling units [6, 7].

Four fundamental trade-offs have been identified [8]: deployment efficiency—energy efficiency to balance the deployment cost and energy consumption in the network, spectrum efficiency—energy efficiency to balance the achievable rate and energy consumption, bandwidth—power to balance the bandwidth utilized and the power needed for transmission, and delay power—power to balance the average end-to-end service delay and average power consumed. Figure 10.2 illustrates these trade-offs [8].

Green communication satisfies the same criteria for green technology [9, 10]:

a. It minimizes the degradation of the environment.
b. It has zero or low GHG emission.
c. It promotes healthy and improved environment for all forms of life.
d. It conserves the use of energy and natural resources.
e. It promotes the use of renewable resources.

Key techniques of green communication mainly include cognitive network, network coding, and smart grid [11]:

- *Cognitive network:* This network can effectively improve the spectrum resource utilization efficiency and the network transmission performance. Cognitive radio plays a crucial role in improving the utilization efficiency of radio spectrum. It is capable of exploiting the residual bands when their licensed users (known as primary users) are not broadcasting on those frequencies, and to free up the channel as soon as the primary users want to access it. As illustrated in

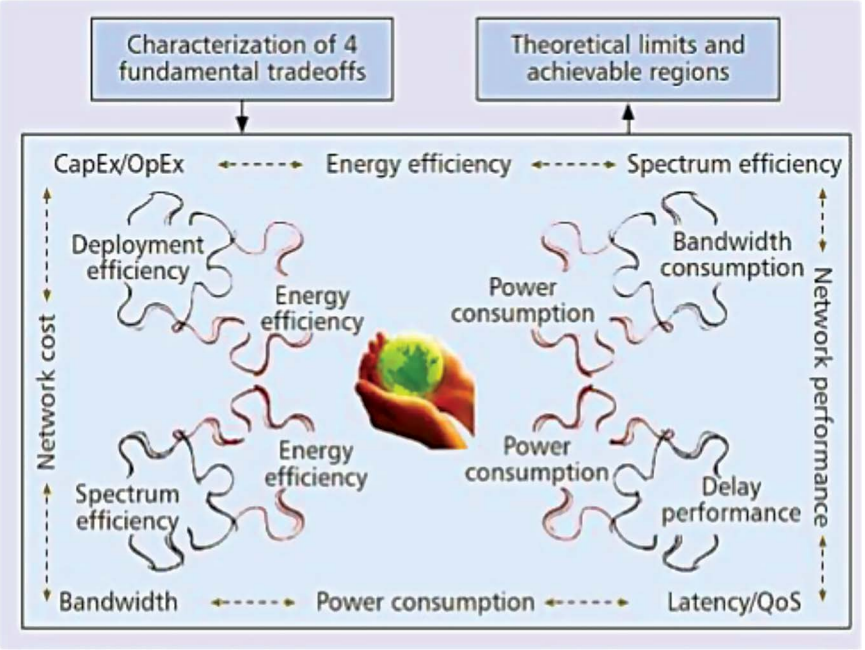

FIGURE 10.2
Fundamental trade-offs [8].

Figure 10.3, cognitive radio adds a dimension of intelligence, learning, and adaptation [12].

- *Network coding:* This involves removing redundant routes to improve the network throughput. Network coding technology saves network bandwidth and improves the link utilization.
- *Smart grid:* The main objective of the smart grid is to bring reliability, flexibility, efficiency, and robustness to the power system. The

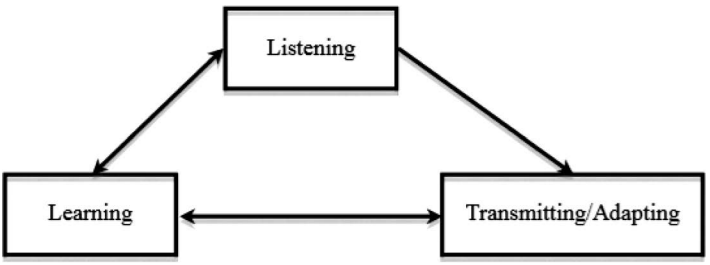

FIGURE 10.3
How cognitive radio works [12].

smart grid does this by introducing two-way data communications into the power grid. It provides the modern electricity grid with a high-speed, fully integrated, two-way communication technological framework. It facilitates measuring, monitoring, protecting, and controlling functions.

10.3 Green Networking

Green networking (also known as energy-efficient networking) refers to minimizing utilization of energy through use of energy-efficient technology, renewable energy resources, and environmental friendly consumables. It addresses unnecessary energy consumption in the two areas: wired networks and wireless networks. Traditionally, wired networks have been designed without considering energy efficiency. But reduction of unnecessary energy consumption is becoming a major concern in both wired and wireless networks. Green networking covers all components of the network, including personal computers, switches, routers, communication media, and other devices connected to the network. Energy-efficient networking targets the reduction of energy consumption by these components. Some of the goals of green networking include [13]:

i. Reduction of energy consumption.
ii. Improvement of energy efficiency.
iii. Consideration of the environmental impact of network components from design to end of use.
iv. Integration of network infrastructure and network services.
v. Making the network more intelligent.
vi. Compliance with regulatory reporting requirements.
vii. Promotion of a cultural shift in thinking about how we can reduce carbon emissions.

Green networking is the practice of selecting energy-efficient networking technologies and products, and minimizing resource use. Its practices include [14]:

1. Implementing virtualization.
2. Practicing server consolidation.
3. Upgrading older equipment for newer, more energy-efficient products.

4. Employing systems management to increase efficiency.
5. Substituting telecommuting, remote administration, and videoconferencing for travel.

Although investing in green networking may require an initial cash outlay, the products and practices involved typically save money once put in place.

Virtualization as the name implies is creating a virtual environment. Instead of running different servers separately, through virtualization all the servers can run on one to two computers [15]. Virtualization can be applied to different resources, including network links, storage devices, and software resources.

Green networking research stems from different observations on the root causes of energy waste [16]: (1) adaptive link rate, (2) interface proxying, (3) energy-aware infrastructure, and (4) energy-aware applications.

10.4 Energy-Saving Techniques

The design of energy-efficient networks is important for green communications and networking. Energy efficiency in communication systems relies mainly on the power consumption of individual components that comprise them. It is associated with reduced energy consumption. In principle, reducing the energy consumption of communication networks can be achieved in the following ways [17]:

- *Network planning:* Optimize the physical placement of resources and enable the potential to power off network equipment.
- *Equipment reengineering:* Introduce low-energy network equipment and devices.
- *Network management:* Optimize the operation of network equipment as well as network-wide protocols and mechanisms by adjusting network resources based on the users' demand.
- *Renewable energy:* Reduce the energy consumption from power grid by supplying energy from alternative sources, such as wind, micro hydro, solar, tidal, geothermal, etc., which are also called green energy.
- *Social awareness:* Educate users to avoid wasting energy.

Energy-saving techniques will increase the efficiency of the network and reduce the economic costs as well as environmental impact.

10.5 Applications

Common applications of green communication and networking include energy efficiency in wireless networks, cellular networks, mobile networks, vehicular ad hoc networks (VANETs), and smart grids. We have covered smart grids earlier.

- *Green wireless communication:* The most boisterous revolution in communication has been the rapid evolution in wireless and mobile communication. Wireless communication is the most emergent and accepted area of communication field. Green wireless communications strive for improving energy efficiency as well as reducing environmental impact. It can be achieved with the use of green handover, green codes, green electronics, green power amplification, green antennas, green manufacturing, and green base transceiver stations using renewable energy sources [18]. Other issues related to green wireless networks include green cellular base station, energy-efficient mobile terminals, green ad hoc and sensor network, green cognitive radios, electromagnetic pollution mitigation, and energy-efficient signal processing techniques [19]. Green wireless communication will provide energy-efficient communication. Green communication among mobile and wireless networks enables providing potential benefits for balancing the resource usage and saving energy. Green communication becomes the utmost important and promising research topic for future mobile and wireless networks. The next-generation wireless networks should be able to provide high-speed Internet access anywhere and anytime.
- *Cellular networks:* A cellular network is a radio network distributed over land areas known as cells, each served by at least one base station. A typical cellular network consists of three main elements: a core network that takes care of switching, base stations providing radio frequency interface, and the mobile terminals used in making voice or data connections [20]. The cellular network is the largest factor contributing to the mobile industry's energy consumption. As a result, energy efficiency in cellular networks has been a growing concern for cellular operators. Green communication technologies are widely preferred and deployed for achieving energy efficiency.
- *Green mobile communications:* It has been observed that mobile operators are among the top energy consumers. The explosive growth of mobile communications gives rise to a compelling case to reduce the electromagnetic pollution. Causes of carbon footprint in mobile communications include manufacturing of mobile devices, radio frequency (RF) transmission, charging of batteries, electricity

consumption of base stations, data centers, and data transport, operation of offices, stores, vehicle fleet, and business travel [21]. Green mobile communications is in tune with the trend of reducing carbon footprint and emission of GHGs [22]. To enable power saving, mobile terminals when not in use can operate in either sleep mode or idle mode.

- *VANETs:* VANETs provide communications required to deploy intelligent transportation, which is an emerging transportation system that applies ICT to enhance safety and mitigate traffic congestion. With the proliferation of electrical vehicles powered by finite batteries, any power consumption should be minimized to extend the range of vehicles. The power consumption by VANETs is becoming a concern and the adoption of green communications and networking is highly desirable [23].

10.6 Green Metrics

Green metrics (or energy efficiency metrics) are important in green communications and green networking. The metrics provide information that can be used to assess and compare solutions and technologies. Energy-efficient metrics are needed to measure the energy consumption of a network. A number of metrics have been proposed to efficiently evaluate the effort for achieving green communications systems. The metrics have been classified in three main categories: component-, equipment-, and network-level metrics. Greenness metrics (such as Green Performance Indicator and Carbon Emission Calculator) are directly involved into CO_2 emission. Component-level metrics measure the performance of a specific component of a wireless device such as antenna, power amplifier, power supply, etc. Equipment-level metrics are used to investigate the energy efficiency of a given equipment such as end user terminals or base stations. Network-level metrics assess energy efficiency at the network level [24].

10.7 Benefits and Challenges

Adopting green communication technology helps individuals and businesses to reduce power consumption and lower the costs of operation. Green Networking helps to reduce the carbon footprint of the ICT industry. More benefits of green communications and networking include [25]

the following: (1) reduces energy-related costs, (2) attracts new customers and increases sales, (3) may be eligible for tax incentives, (4) boosts workforce morale and innovations, (5) makes societal impact, (6) gains a competitive advantage, and (7) enters new markets with environmentally focused products.

Rising energy costs and environmental policies are some of issues that are driving the need for energy-efficient networking. One of the major barriers for deployment of energy-saving techniques in real networks is their integration in actual network protocols. The energy consumption of Internet is becoming huge due to an increase in the number of connected devices. The challenge is to make the increase of the Internet operational efficiency faster than the rate of traffic growth [17]. It is not easy to characterize the different sources of energy consumption due to lack of precise and realistic models in support of the design of protocols and algorithms. Other challenges include scalability, reliability, interoperability, and security.

10.8 Conclusion

The exponential growth of mobile and wireless systems makes it difficult to ignore their carbon footprint. Green communication and green networking are of utmost importance for the future mobile and wireless networks. Their goal is to drive the technology toward "Going Green." It is important that any emerging technology is harmonized with our mother nature. This means better fuel efficiency and better processes would mean even better things for the environment.

The need for adopting green communication and networking has been realized worldwide. Green communications are key to facilitate real smart applications. Green communications and networking will meet the demand of energy efficiency of the next-generation wired, wireless, smart-grid networks, and IoT. They are the new focus of the telecommunications industry. They have attracted significant attention from academia, industry, and government agencies due to their ability to create eco-friendly power-efficient networks. It has been observed that telecommunications applications can have a significant impact on lowering GHG emissions and power consumption. Consequently, organizations are following environment green policies in hiring, training, and running of their business.

For more information on green communication, one should consult books in References [12, 17, 26–32] and other books available on Amazon.com. One should also consult the journal exclusively devoted to it: *IEEE Transactions on Green Communications and Networking.*

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