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EDITOR'S NOTE

Green Wireless Communication Networks

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The increasing usage of conventional energy sources such as oil and coal poses a wide variety of environmental issues, including climate changes, air pollution, and acid rain. At the same time, the prices of conventional energy sources are soaring while the world's energy consumption is ever increasing. In order to provide sufficient, environment-friendly, and low-cost energy to sustain economic growth and raise living standards across the world, innovation and development of alternative energy sources are required. Green energy, which refers to the eco-friendly renewable energy replenished from natural resources such as sunlight, wind, and geothermal heat, is expected to be a promising alternative to conventional energy sources. According to the 2012 Renewables Global Status Report (GSR), the development of green energy techniques has dramatically reduced the cost of green-powered electricity. For instance, the prices of photovoltaic modules and onshore wind turbines have dropped by 50 percent and close to 10 percent, respectively. Both the decreasing cost and the environmental concerns motivate the usage of green energy. In 2011, renewable sources supplied 16.7 percent of global energy consumption, with an increasing share of renewable energy and decreasing utilization of traditional energy. Moreover, investment in renewables has increased by 17 percent to a record of $257 billion in spite of the widening financial crisis in Europe, and 118 countries reached renewable energy targets.

On the other hand, over the past decade, the demand for high-rate multimedia wireless communication services has increased dramatically, especially with the popularity of smartphones, tablets, and other mobile devices. The need for media-rich input/output, computation, and communication forces mobile users to charge their devices much more often. This undesirable phenomenon will worsen over the next 10 to 20 years due to the increasing gap between the mobile terminal demand for energy and the offered battery capacity. At the same time, service providers have been adding more and more base stations (BSs) to meet a higher service demand, leading to roughly 2 percent of total CO_2 emissions by the telecom industry, which could increase up to 4 percent by 2020 according to an Alcatel-Lucent forecast. A large portion of the service providers' operational costs is due to energy consumption. As a result, recently there have been various research and development (R&D) initiatives worldwide toward energy-efficient and green wireless communications and networking, in order to reduce the cost of high energy consumption of the wireless systems for both mobile users and service providers, which will also reduce the negative environmental impacts.

There are many studies on increasing energy efficiency to construct a green wireless communication network. Based on recent advances in green techniques, it is becoming possible to use alternative energy sources to power wireless network devices, including BSs, access points (APs), and relay nodes (RNs), to achieve a sustainable green wireless communication network. Several research projects on green communications, such as OPERANET, EARTH, and Green Radio, have sprung up worldwide to increase energy efficiency in provisioning high-data-rate services. However, unlike traditional energy sources, green energy sources vary in capacity and are highly dependent on the location and weath-

er, which makes it a very challenging task to exploit green energy sources in the deployment and management of wireless communication networks. Therefore, the fundamental design criterion in developing green wireless communication networks is shifted from energy efficiency to energy sustainability due to the nature of green energy. In what follows, we briefly discuss two research areas in developing the next-generation green wireless networks.

Network Infrastructure

For wireless networks powered by traditional energy sources, one objective in the network design and operation is to minimize energy consumption. However, in the context of green wireless networks, we should also consider the variable and intermittent nature of renewable energy sources. For instance, the energy generated by a wind turbine may be intermittent, and the solar panel may provide varying energy dependent on the weather and season. To deal with the variations in energy supply, batteries can be used to store the harvested energy for future usage. With large-capacity rechargeable batteries, one possible approach is to model the green energy sources as charging/discharging energy buffers. Depending on the analysis of energy charging/discharging processes, remaining energy, and service demand statistics, the energy buffer model can be developed to predict whether or not the network will have sufficient harvested energy to support the service demand. If the network will overdraw energy from the energy buffers with a high probability, the wind turbine and/or solar panel should be resized to ensure that the network can provide continuous wireless access for its users.

Furthermore, in terms of green BSs and relay stations, network planning and deployment should account for both service demand and different energy source charging capabilities at various locations within the network coverage area. To ensure quality of service (QoS), the number and locations of the network entities should be carefully determined. Due to the relatively high capital expenditure involved in deploying the green entities, how to deploy a minimal number of the network entities to provide full coverage and meet QoS requirements needs to be investigated.

Networking Algorithms and Protocols

To provide multimedia communication services, green wireless communication networks should support diverse QoS requirements via effective and efficient resource allocation, such as subcarrier radio resources, transmission power control, and packet transmission scheduling. In addition, the energy budget at both BSs/relay stations and mobile devices should be considered, especially taking into account the dynamic nature of green energy sources. Previous research on minimizing energy consumption has been limited mainly to wireless sensor networks, where the sensors have very limited power capacities and low data traffic load with no (or low) node mobility. Therefore, many existing solutions cannot be directly applied to broadband mobile communication services. On the other hand, in multimedia mobile communications, reducing power consumption has been studied from a perspective of limiting interference for a maximal radio frequency reuse, and overprovisioning of service quality is the dominant approach in which not much constraint is placed on energy consumption. In green wireless networking, however, enabling energy-efficient communications comes at the cost of service quality, such as violating required performance in data delivery delay and accuracy. Moreover, minimizing energy consumption does not necessarily maximize the network lifetime. Many challenging research issues arise in networking algorithm/protocol development for service provisioning, such as: How does the new objective of minimal energy consumption change the fundamentals in wireless networking? How can energy efficiency be incorporated into mathematical modeling for network protocol development? What are the trade-offs between energy consumption and service quality?

In conclusion, to deal with environmental concerns, reduce energy cost for service providers, and prolong mobile device operation time per battery charging, a promising approach is to develop green wireless communication networks. However, we face many research challenges in integrating green energy technologies with wireless networking technologies for network deployment, developing energy-efficient networking algorithms and protocols, and satisfactory service quality provisioning. Developing innovative solutions requires interdisciplinary expertise and efforts from various research communities including networks, power systems, devices, and circuits. This Editor's Note only introduces some related research topics with a focus on network infrastructure and networking algorithms/protocols.