Chapter 21
Long-Endurance Scalable Wireless Sensor Networks (LES-WSN) with Long-Range Radios for Green Communications

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Abstract. Two paradigm-shifting innovations are presented that have potential to enable an affordable Green Communications (GC) class: large-scale, low-cost environmental and endangered species monitoring using a generation of new unattended, long-duration wireless sensors. We first describe why existing solutions based on short-range radios have failed to address this key GC regime, and how the proposed LES-WSN innovations, namely long-range radios and two-tier (one-radio) architecture, makes low-cost wide-area environmental monitoring a reality. By utilizing high transmission power, long-range radios drastically reduce overall system cost when covering large areas. By combining the latest Long-Term Evolution waveform with this high transmission power radio hardware, we achieve both long communication range and high data rate (2+Mbps) simultaneously and at extremely high battery efficiency. The two-tier, one-radio architecture allows for only a small number of nodes to relay the sensor data, relieving vast number of sensor nodes from the burden of relaying. In addition, it eliminates the need for sensor nodes to wake up frequently and periodically, enabling mobile sensors for endangered species monitoring. Several new GC applications that become possible by the proposed LES-WSN paradigm are described, along with field experiment results that validate the claimed enabling benefits.

21.1 Introduction

Green Communications (GC) is a nebulous terminology that often refers to a subset of Information Technologies (IT) designed to enable people or devices to exchange information (voice, data, video) consuming as minimum energy as possible (subject to maintaining “reasonable” communication quality). The ever-pervasive penetration of wireless portable devices such as cell phones, smartphones, tablets, MP3 music players, and laptops into our daily lives has
accelerated the advances in GC technologies since each and every device is expected to maximize its battery life. Naturally, maximizing the efficiency of energy usage is the single most important metric for GC devices and systems. On the other hand, GC is also frequently used to represent an initiative aimed at preserving the nature via environmental monitoring with unattended sensors. For example, “Planetary Skin” is a multi-year joint effort by NASA and Cisco to capture, analyze, and interpret global environmental data using satellites, airborne-based, and land-based sensors\(^1\)\(^2\).

Wireless Sensor Networks (WSN) is a unique intersect of these two GC aspects (both as GC technology and GC application), since its primary objective is to deliver vital information about the environment (collected by sensors) using as little energy as possible. As a GC technology, a WSN system seeks long operational lifetime (months or years) so that ultimately, no battery change is needed during the entire monitoring period. As a GC application, a well-designed, strategically deployed WSN system in a remote area can collect near-real-time information about endangered species and the overall health of the environment in a large scale\(^3\). Consequently, it is no surprise that the growing interests in GC from policy makers, engineers, entrepreneurs and the public have produced tremendous activities in the design, development, and commercialization of emerging WSNs for various coverage sizes and applications, ranging from periodic monitoring with home-networked sensors to wide-area remote environment sensing.

A fundamental requirement for WSNs to remain a successful and enabling force in the GC marketplace is to adopt the highest energy efficiency wherever possible (ultra-low-power sensors, clocks, communication components, high-capacity batteries, etc.) because unattended environmental sensors are typically battery powered and an energy-inefficient sensor system requires frequent battery change or recharging. But, battery replacement can be extremely costly or impossible because of the labor involved in accessing the deployment sites that are either unsafe or hostile to humans. Therefore, energy efficiency has served a fundamental consideration in the WSN system design metrics, and consequently, led to miniaturization of sensor systems, including its communications components and protocols (e.g., smart dust\(^4\)).

However, maximizing the energy efficiency of individual sensor nodes alone is not sufficient to address one major GC sector: a growing list of emerging WSN applications such as wide-area long-term monitoring and tracking applications. For example, U.S. federal and state governments have various mandates to monitor the health of the environment such as air quality, water quality, vegetation growth, and tracking of endangered species. Reliable, self-organizing, and scalable WSNs capable of remote operations have multiple Department of Defense (DoD), Department of Homeland Security (DHS), national and state parks, and

\(^{1}\) http://www.nytimes.com/gwire/2009/03/03/03greenwire-nasacisco-project-to-flash-planetary-skin-9959.html  
\(^{2}\) http://www.planetaryskin.org  
\(^{4}\) http://robotics.eecs.berkeley.edu/~pister/SmartDust