The Wireless Watershed at the Santa Margarita Ecological Reserve

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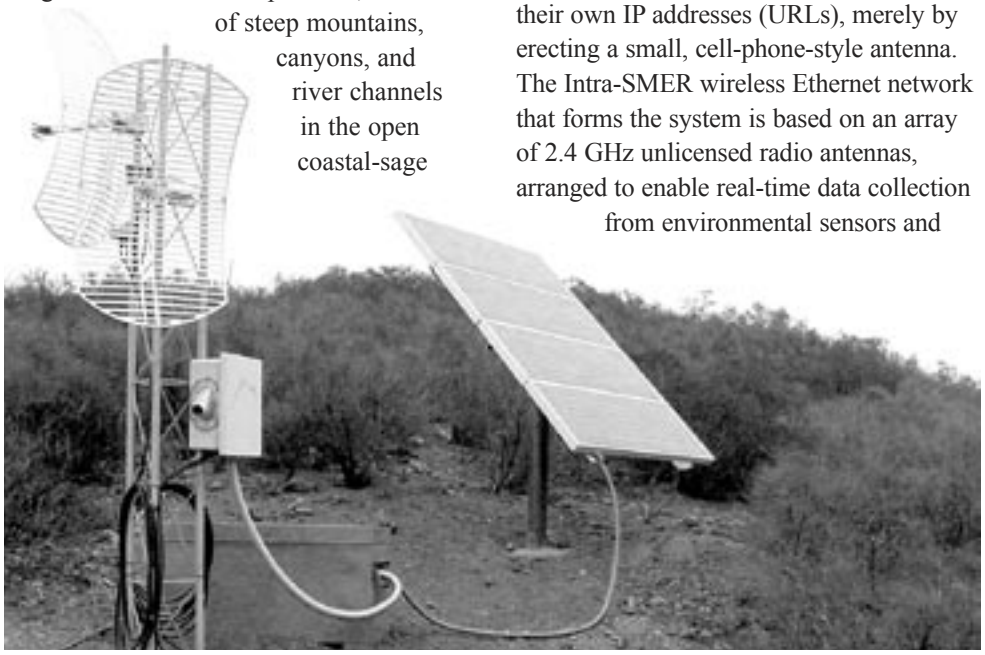
Southern California is famous for its beaches, traffic, and verdant suburbs. It relies so heavily upon external supplies of water, power, and people that one may easily forget that the landscape is still mostly natural. Little is known about the interactions between the suburban settings and the natural cocoon of mountains, canyons, and rangelands that encompass them. At the Santa Margarita Ecological Reserve (SMER) in Southern California, scientists are beginning the daunting task of instrumenting the rugged walls and canyons of the coastal sagebrush landscape to characterize the workings of the suburban-native interface. In establishing a hydrometeorological window on the rugged Southern California landscape, they are developing and testing important wireless methods for bringing monitoring results from remote sites directly onto the Internet.

Established in 1962, SMER is one of four field stations that make up the San Diego State University (SDSU) Field Stations Program. SMER encompasses 4,344 acres of steep mountains, canyons, and river channels in the open coastal-sage countryside in southwestern Riverside and northwestern San Diego counties in Southern California, about 10 miles inland near the suburbs of Temecula and Fallbrook. SDSU manages the reserve cooperatively with the U.S. Bureau of Land Management, the Metropolitan Water District of Southern California, The Nature Conservancy, and the California Department of Fish and Game.



Repeater station at the SMER.

In addition to providing a natural laboratory at the suburban/rural interface, SMER provides a test site for new wireless technologies and sensor networks. A wireless communication system has been installed that provides a "bubble" of connectivity over 65 percent of the reserve. The sensing technology that is being deployed at SMER has the potential to be a prototype for high-density environmental monitoring in urban and wilderness settings worldwide.

Wireless Infrastructure

Anywhere within this system, instruments can be linked directly to the Internet, with their own IP addresses (URLs), merely by erecting a small, cell-phone-style antenna. The Intra-SMER wireless Ethernet network that forms the system is based on an array of 2.4 GHz unlicensed radio antennas, arranged to enable real-time data collection from environmental sensors and imagers anywhere in the system. The network was constructed on the basis of extensive GIS and ground-truthing to identify those locations within the reserve that offer the best vantage points and greatest reserve coverage from the fewest antennas or telecommunications (TC) sites. Data transmission is accomplished by a network of radios and routers. The combined views from the five TC sites allow coverage of almost 2,800 acres of the reserve, in canyons, around steep and undulating terrain, and in a variety of habitats. Additionally, the wireless coverage provided by the network is flexible. By redirecting an antenna or adding another radio to a TC site, service to new research sites can be added. Three of the five TC sites are too remote to receive line power and therefore rely on solar power systems that are designed to power them continuously for years.

The wireless communication and sensor networks at SMER make monitoring much easier but are obtained in the face of a number of complicating factors. The topography is rugged and the line-of-sight relations required by wireless connections are often difficult to obtain. River channels are among the most difficult locations in which to make the connections because of steep canyon walls. Installation and repairs are often difficult because trails are rough and some locations are only accessible by foot. Some of SMER is controlled by federal agencies (U.S. Bureau of Land Management and U.S. Fish and Wildlife Service) that impose restrictions on wilderness intrusions. Because AC power is available in only a few locations, solar or battery power is often required. The river channel is prone to flooding; in fact, a heavily anchored meteorological tower was toppled and torn out during one of the past winter's heavier rainstorms. However, these

obstacles—which are also encountered in other network settings—are being overcome at SMER by hard work and careful planning.

Hydrometeorological Data Collection

Scientists from around the world are beginning to use the wireless data-transmission capabilities at SMER to obtain real-time access to their research projects and to test wireless methods for use elsewhere. While much of the research at SMER has an ecological focus, researchers in other disciplines are finding the site's protected, undeveloped setting and wireless communication facilities well-suited to their needs. A group that includes researchers from Scripps Institution of Oceanography at the University of California San Diego (Scripps), the U.S. Geological Survey (USGS), and the San Diego Supercomputer Center (SDSC) worked at SMER to develop a program to answer questions about the water balance and variability of weather and water in the Southern California landscape. In addition, they are monitoring airflow and other meteorological properties related to airborne pollutant loadings and sources of water and air pollution.

Precipitation, wind speed and direction, air temperature, relative humidity, barometric pressure, and solar radiation are currently being collected at SMER, with additional parameters on the drawing board. To date, 20 meteorological towers have been installed and are presently being outfitted with sensors, specially designed data loggers, and spread-spectrum radios. This array should provide some of the highest-density information yet collected over a coastal Southern California watershed.

The SMER staff is currently measuring stream pressure (to calculate stage), temperature, conductivity, and dissolved oxygen at one central location, and the USGS has long-term streamflow gauging stations above and below the reserve. The Santa Margarita River, as it enters the reserve, derives from the heavily suburbanized Temecula basin immediately upstream, and thus provides opportunities for understanding the hydrology of a suburban-rural interface. Soon, hydrologic monitoring by the Scripps-USGS researchers will include stream stages (to calculate stream discharge), water temperature, and conductivity (to estimate total dissolved solids) at several locations along the main stem of the river and in some of its tributaries, including Stone Creek, an unregulated drainage that is relatively unaffected by development. The tributary observations are intended to characterize the near-natural variations of Southern California runoff.

The network of hydrometeorological stations is currently connected to the wireless Internet through three TC sites. These sites receive radio signals from data logger stations as short-range spread-spectrum signals and convert the dataflow into a wireless Internet protocol. The TCs then transmit the information into the intra-SMER wireless network, which, in turn, is connected to HPWREN, the noncommercial High Performance Wireless Research and Education Network (see page 16) that provides Internet access to the SMER data.

The weather elements are sampled once per second and averaged each minute. Data are stored at SDSC and eventually will be available from the Western Regional Climate Center. The data are available to the public through the ROADNet Web site, at roadnet.ucsd.edu/.

The Scripps researchers and their partners plan to use weather and stream data to investigate microclimates, temporal and spatial variations of storms, sea breezes and Santa Ana winds, and water balances as the basis for water and air quality studies. The effects of evapotranspiration on the discharge of the Santa Margarita River and its tributaries will be studied, and the water budgets of the Santa Margarita River, regulated through substantial injections of fresh water upstream of SMER, and of unregulated Stone Creek will be compared.

Future Plans

This fall, the research team plans to install additional meteorological towers within SMER, and in the longer term, they hope to extend the network beyond the boundaries of SMER into upper and lower parts of the river's watershed. Eventually, they plan to couple these hydrometeorological observations into a watershed model to synthesize the water balances and other hydrometeorological aspects. With their SDSU partners, the researchers are discussing an expansion of their emphasis from the physical aspects of weather, climate, and the water balance to studies of air and water quality and to fire-protection networks. The weather towers, data loggers, and communications structures are also available to support other kinds of sensors, so it is hoped that new experimental efforts will take hold as this project evolves.

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