Novel long range wireless sensor network monitors remote areas

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Imagine the challenge of real-time monitoring of the moisture content in soil across hundreds of acres of land, the continuous functioning of equipment in the arctic tundra, or the movement of clandestine materials in remote parts of the world. Now imagine the monitoring happening over many months or years and far away from the scientist, rancher, or soldier that needs this information. Is there an affordable space-based solution or must scientists be confined to complex terrestrial solutions? The answer may lie in a novel and innovative Los Alamos National Laboratory technology. Over the past 75 years the Laboratory has developed and designed many pieces of low-power, ruggedized sensors for use with the military, the environment, and in space, among other uses.

Continued innovations in sensing and communications technology have significantly increased the demand for real-time monitoring and automation. Some such areas include manufacturing, health-care, transportation, security, and the environment. As a result, growth has exploded in applications for wireless sensor networks (WSN) in recent years. However, the diversity of application requirements has resulted in challenges to standardization and utilization.

Wireless sensor networks of the past were developed for indoor applications and were not suitable for vast outdoor extreme environments. Additionally they were expensive to deploy and maintain, required specialized programming skills, and due to the large routing paths required to support such a system, the networks were quite unreliable and difficult to manage. Current solutions have been restricted to outdoor networks covering smaller geographic areas (e.g. 1 sq. km). Using longer range radios to make routing paths smaller in length requires high transmit power requirements supported by large, bulky batteries. Therefore a new strategy was needed and this industry may now be on the verge of a very positive disruption due to the development of a Long Range Wireless Sensor Network. A Laboratory research team, led by Janette Frigo of the Lab's Space Data Science & Systems group, has developed a novel system which covers large geographic areas using a self-healing, self-forming mesh network of long range radios while retaining energy efficiency through a novel combination of hardware and communication design.

Significance of the work

Over decades Los Alamos has repeatedly addressed the limitations of existing technology in the support of arctic climate monitoring, western rangeland management, and storm-water runoff for environmental compliance over the Laboratory's approximately 40 square mile facility. These diverse applications have some characteristics in common. The sensor systems were deployed in remote locations with restricted access and often extreme environments with limited resources (e.g., no access to power) across the world. The systems required persistent monitoring (24/7) over periods of years with high data transmission reliability. A multi-hop network with ad hoc self-forming, self-healing properties is needed in these environments due to generally poor line-of-sight (LoS) communication links from adverse terrain, bad weather, and electromagnetic or radio frequency interference. A self-forming network means the nodes discover their route back to the master node (sink node) and have no knowledge of their routes prior to deployment in the network. This important feature allows a field technician to place the nodes ad hoc for installation. A self-healing network is required so if a node fails, its failure will not take down the rest of the system because the other nodes are able to discover alternate paths. These properties are critical to maintain uninterrupted service in extreme, remote environments.

Early on the Laboratory team found that Commercial-Off-The-Shelf (COTS) parts did not meet their needs because the hardware architecture was not designed for scientific computing and did not enable communications protocols that could navigate long range over diverse terrain with unknown physical obstacles. Because of these and other challenges Frigo's team began building their own hardware and developing software.

The Los Alamos research engineers, working with several distinct user communities including those studying climate science, working on environmental monitoring, and rangeland management, developed a robust general purpose combined sensor node with generic ports for sensors and dual communications (satellite or LOS RF). Key features of the Long Range WSN are it is low cost, it consumes low average power (milliWatts continuous or microWatts in sleep mode), and is ruggedized for extreme temperatures and outdoor use in remote environments (arctic to the desert). It has a novel networking protocol that enables scaling to the order of hundreds of nodes (arctic to the desert). The hardware is configured to operate in a stand-alone or LOS mesh network or both modes of communication. The sensor node has two modes of operation, continuous or scheduled monitoring. In Figure 2, the system is continuously monitoring for an "event" (milliamps) and in other systems, the hardware collects data on a schedule, i.e. every half hour it wakes up, collects data, and transmit data, then returns to a sleep mode. Average power for scheduled data collection is in the microWatts range. During development the team implemented a system with node-to-node distances up to 19Km (12mi) which was deployed on the Stormwater Runoff project in the Los Alamos watershed (2016). These node-to-node distances have been operating for nearly 2 years, 24/7 in a network with 60 to 120 nodes (network size varies as we deploy nodes from 2016-2017). In 2013-14 The team of Los Alamos scientists in Earth System Observations (EES-14) were researching the effect of reduced snow fall on arctic plants and connected their sensors to Frigo's system for 24/7 monitoring and transmission near Abisko Station Sweden in the Arctic Circle. That system operated continuously for over 2-years with temperatures as low as -25 C.

Achievements

After solving many of the challenges found in COTS hardware, Frigo and her team further developed their system based on the needs of the scientists using the equipment. Transmitted data sent to a user's server can now be processed and stored in a database and messages are sent to the user community enabling the users to access their data in near real-time. An operator can monitor system health and data integrity and send commands to the master, for example: changing network parameters, data collection rates or sensor node configurations. An extremely capable flexible node is the basic building block of the network. At the core of the node is a modern System on a Chip (SOC) designed for energy efficient computing with flexibility that allows the team to optimize the node design for their class of applications and distinguishes their system from competitors.

One future application of the Long Range WSN is on a ranch near Las Vegas, NM that now uses COTS hardware for a system to improve ranch management of pastures. The system monitors such things as daily rainfall, soil moisture content, wind speeds, radiation, etc. to determine if the pasture is stressed due to climate impacts and thus, how long a pasture needs to rest from livestock activity. The current system requires manual collection of data. The LRWSN technology will use LOS RF mesh communication to collect data and transmit to the master node at the ranch house and thus, connect to the rancher's computer. If the master node is located in a remote location, the data collected can be transmitted via satellite to the rancher's computer. This same type of system could be used by crop farmers or others in vast and/or remote areas that have little or no infrastructure, power, or cellular reception. The mesh network combined with satellite communication capability provides 2-way communication with nodes anywhere on the earth and are designed for monitoring over 5-10 years continuous service using photovoltaic power and/or rechargeable batteries. This has been proven in two deployments in Selawik, Alaska and above the Arctic Circle in Abisko Station, Sweden. Working with industry representatives from across the State, Janette Frigo received the Principle Investigator Excellence Award from the New Mexico Small Business Association (2016) for her solving New Mexico's small business challenges. In addition, due to the use of the Long Range WSN technology on the Stormwater project, the team received a Pollution Prevention Award (2016) from the Laboratory for reducing unnecessary transportation and labor costs to restricted areas.

The Long Range Wireless Sensor Network hardware is currently in its third iteration of development, being fine-tuned and optimized and a patent is pending. The team has demonstrated the system uses ultra-low power, can operate continuously for 1-5 years, operational temperatures range from -40 °C to 85 °C (-40° to 185°F), has the ability to manage, compress or classify raw data before transmission, and can scale to 120-200 nodes. The team has simulated 400-1000 nodes and the next phase of development will include the addition of encryption and GPS capabilities to the hardware design. The team is currently designing a standard connectivity port for other high data rate sensors such as imaging sensors. Additionally, data compression and in situ data processing techniques for high data rate sensing applications is an on-going research objective.

Depending on who the users are and the problems they're addressing, Frigo and her team are able to better design the system to meet user's needs. Processing at the sensor is enabling for many important applications. Future use for the Long Range WSN may include monitoring for the environment, rangeland and crop health, environmental intelligence and equipment performance, health monitoring of distributed power structures including solar farms. Future security applications may include monitoring for the movement of radiological materials, International Atomic Energy Agency (IAEA) facilities, the identification of movement or activity, and the security of perimeters, buildings, structures, national borders and ports.

Transmitting information to the user in a timely fashion so the user knows the sensor data is normal, the perimeter is not disturbed, and the environment is not dangerous is paramount to remote sensing. This LANL technology has achieved a great milestone toward a sophisticated, affordable and easy to use remote sensing solution. This adds yet another chapter in the Laboratory's distinguished history of developing low-powered ruggedized sensor and communication systems.

The research team

Lab researchers include: Janette Frigo, Tracy Gambill, Hudson Ayers, Shawn Hinzey, Kari Sentz and Xiaoguang Yang of the Space Data Systems group; Sanna Sevanto of Earth System Observations; Kevin McCabe, Don Enemark of Michael Proicou of X-Theoretical Design; Stephen Judd of Integrated Design & Assessment; Armand Groffman and Alexandra Saari of Environmental Services; and Vinod Kulathumani of West Virginia University.

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This research supports Los Alamos National Laboratory's Global Security mission area and the Science of Signatures and Information Science and Technology science pillars. The work promotes data at scale and multi-source integration for forward deployment, and adaptive sensing systems for national security signatures.

Caption for image below: *Long Range Wireless Sensor Network hardware assembly.*