Mesh wireless sensor networks: Will their potential ever be realized?

Although the idea of mesh wireless sensor networks is not new, the realization of their many benefits have gone largely unrealized. The low success rate of most wireless systems makes the accomplishments of this Johns Hopkins group unique.

The ability to measure soil moisture and temperature is vital to ecologists who work in heterogeneous environments because these parameters are major drivers of seasonal dynamics, soil respiration, carbon cycling, biogeochemical functions, and even the types of species living in a certain area. But ecologists' scientific understanding of environmental conditions is hindered when soil moisture measurements disturb the research site, or when field measurements are not collected at biologically significant spatial or temporal granularities. Soil ecologist Dr. Kathy Szlavecz and her husband and computer scientist, Dr. Alex Szalay, both at Johns Hopkins University, are working to solve this dilemma by testing a wireless sensor network (WSN; Mesh Sensor Network), developed by Dr. Szalay, his colleague, computer scientist Dr. Andreas Terzis, and their graduate students. These generate thousands of measurements monthly from wireless sensors. The husband/wife team says that WSN's have the potential to revolutionize soil ecology by generating a previously impossible spatial resolution.

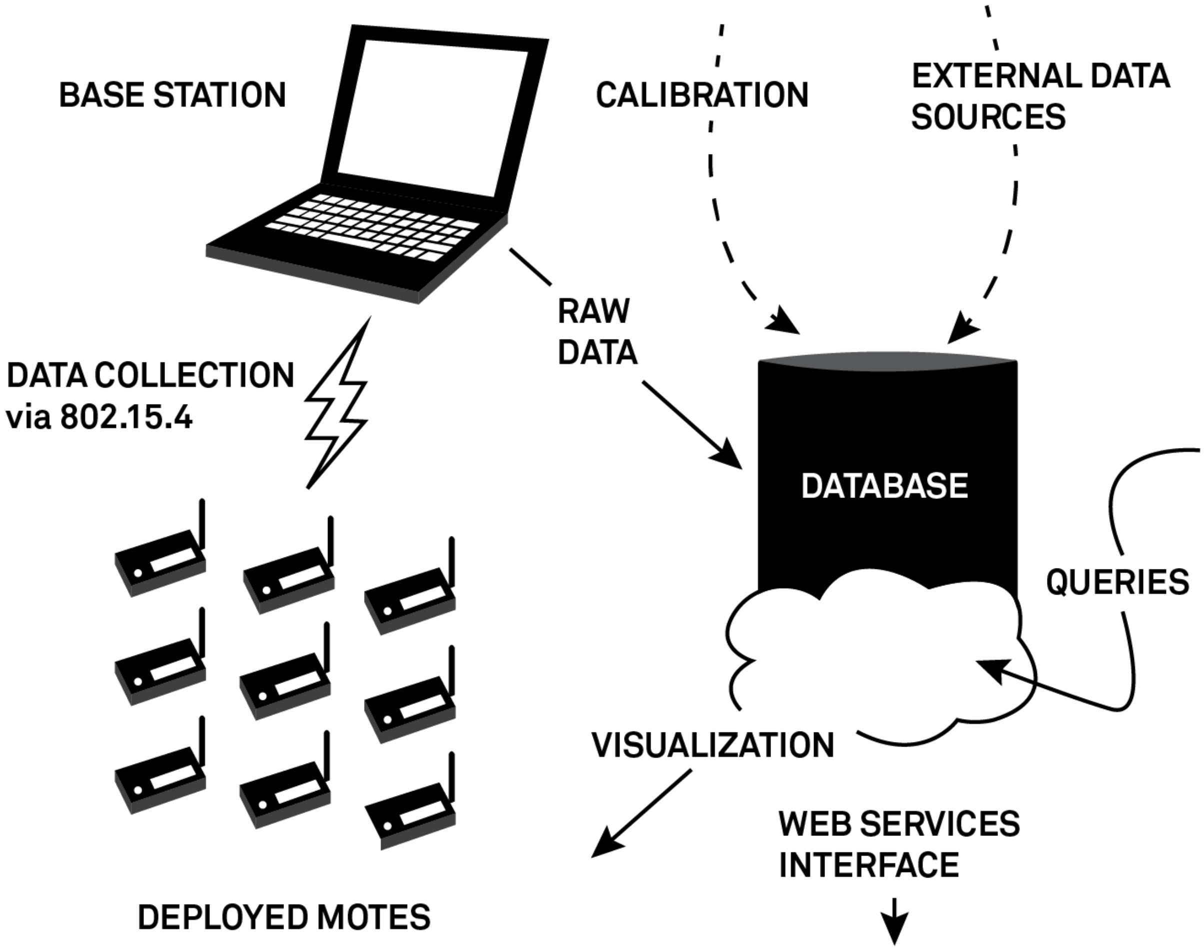

Figure 1. Architecture of an end-to-end mesh network data collection system. (Image: lifeunderyourfeet.org)

What is a mesh network?

In a mesh wireless sensor network, specially designed radio units (nodes) use proprietary or open communications protocols to self-organize and can pass measurement information back to central units called gateways. Different from star networks where each node communicates directly to the gateway, mesh networks pass data to each other, acting as repeater for other nodes when necessary.

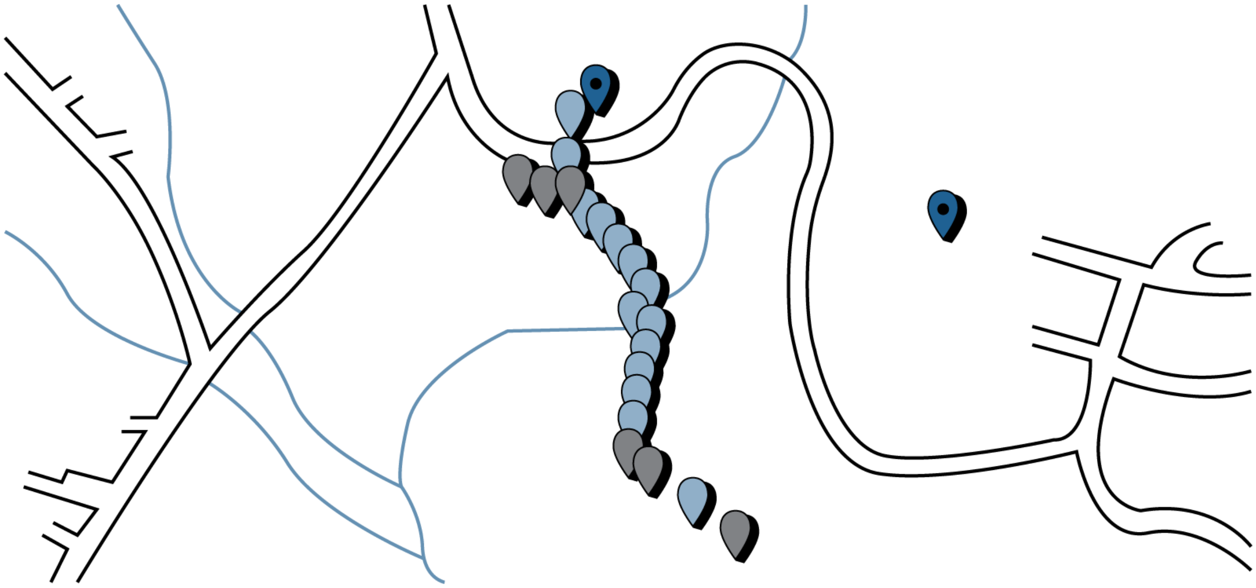

Figure 2. The configuration of 37 sampling locations at the Smithsonian Environmental Research Center (SERC) in Edgewater, MD. Data from this deployment is aimed at understanding the effect of forest age, leaf litter input, and earthworm abundance on soil carbon cycling. (Image: lifeunderyourfeet.org)

With low power and reliability as their goal, they are deployed in dense networks to automatically measure conditions such as temperature and soil moisture. These node measurements are taken every few hours over several months. The data are then uploaded onto computers, where it can be maintained and searched. Kathy explains “Without an autonomous sensor system, experiments in need of accurate information about a multitude of environmental parameters on various spatial and temporal scales require a superhuman effort. The inexpensive nature of these sensors enable scientists to place a high-resolution grid of sensors in the field, and get frequent readouts. This provides an extremely rich data set about the correlations and subtle differences among many parameters, allowing ecologists to design experiments that study not only the gross effects of environmental variables, but also the subtle relations between gradients and small temporal changes.”

Landscape studies benefit from mesh networks

Kathy and Alex have deployed mesh wireless soil moisture sensor networks at several study areas around the state of Maryland. Kathy says, “Once we record the measurements, we can combine that information with observations of soil organisms to better understand how soil organisms and the soil environment interact. This means we can make better predictions about how human activities will affect the soil environment.” In one urban landscape study, Kathy and her team deployed over 100 nodes around a CO_2 flux tower looking at the two major landscape covers in an urban environment: grass and forest. She explains, “We collected data from nodes connected to METER soil moisture and temperature sensors for over two years at these sites, and the system worked quite well. We collected about 180 million data points, and that’s no small feat.”


TEROS 12 soil moisture sensor

Results and challenges

About the performance of the network, Kathy says, “Overall, our experiments were a scientific success, exposing variations in the soil microclimate not previously observed. However, we encountered a number of challenging technical problems, such as the need for low-level programming to get the data from the sensor into a usable database, calibration across space and time, and cross-reference of measurements with external sources.

The ability of mesh networks that generate so much data also presents a data management challenge. Kathy explains, “We didn’t always have the resources or personnel who could organize the data. We needed a dedicated research assistant who could clean, handle, and organize the data. And the software wasn’t user-friendly enough. We constantly needed computer science expertise, and that’s not sustainable.”

The team also faced setbacks stemming from inconsistencies generated by new computer science students beginning work on the project as previous students graduated. This is why the team is wondering if a commercial manufacturer in the industrial sector would be a better option to help finish the development of the mesh network.

What's next?

Kathy and Alex say that mesh sensor network design has room for improvement. Through their testing, the research team learned that, contrary to the promise of cheap sensor networks, sensor nodes are still expensive. They estimated the cost per mote including the main unit, sensor board, custom sensors, enclosure, and the time required to implement, debug and maintain the code to be around $1,000. Kathy says, "The equipment cost will eventually be reduced through economies of scale, but there is clearly a need for standardized connectors for connecting external sensors and in general, a need to minimize the amount of custom hardware work necessary to deploy a sensor network." The team also sees a need for the development of network design and deployment tools that will instruct scientists where to place gateways and sensor relay points. These tools could replace the current labor-intensive trial and error process of manual topology adjustment that disturbs the deployment area.

Future requirements

According to Kathy, wireless sensor networks promise richer data through inexpensive, low-impact collection—an attractive alternative to larger, more expensive data collection systems. However, to be of scientific value, the system design should be driven by the experiment's requirements rather than technological limitations. She adds that focusing on the needs of ecologists will be the key to developing a wireless network technology that will be truly useful. "While the computer science community has focused attention on routing algorithms, self-organization, and in-network processing, environmental monitoring applications require quite a different emphasis: reliable delivery of the majority of the data and metadata to the scientists, high-quality measurements, and reliable operation over long deployment cycles. We believe that focusing on this set of problems will lead to interesting new avenues in wireless sensor network research." And, how to package all the data collected into a usable interface will also need to be addressed in the future.