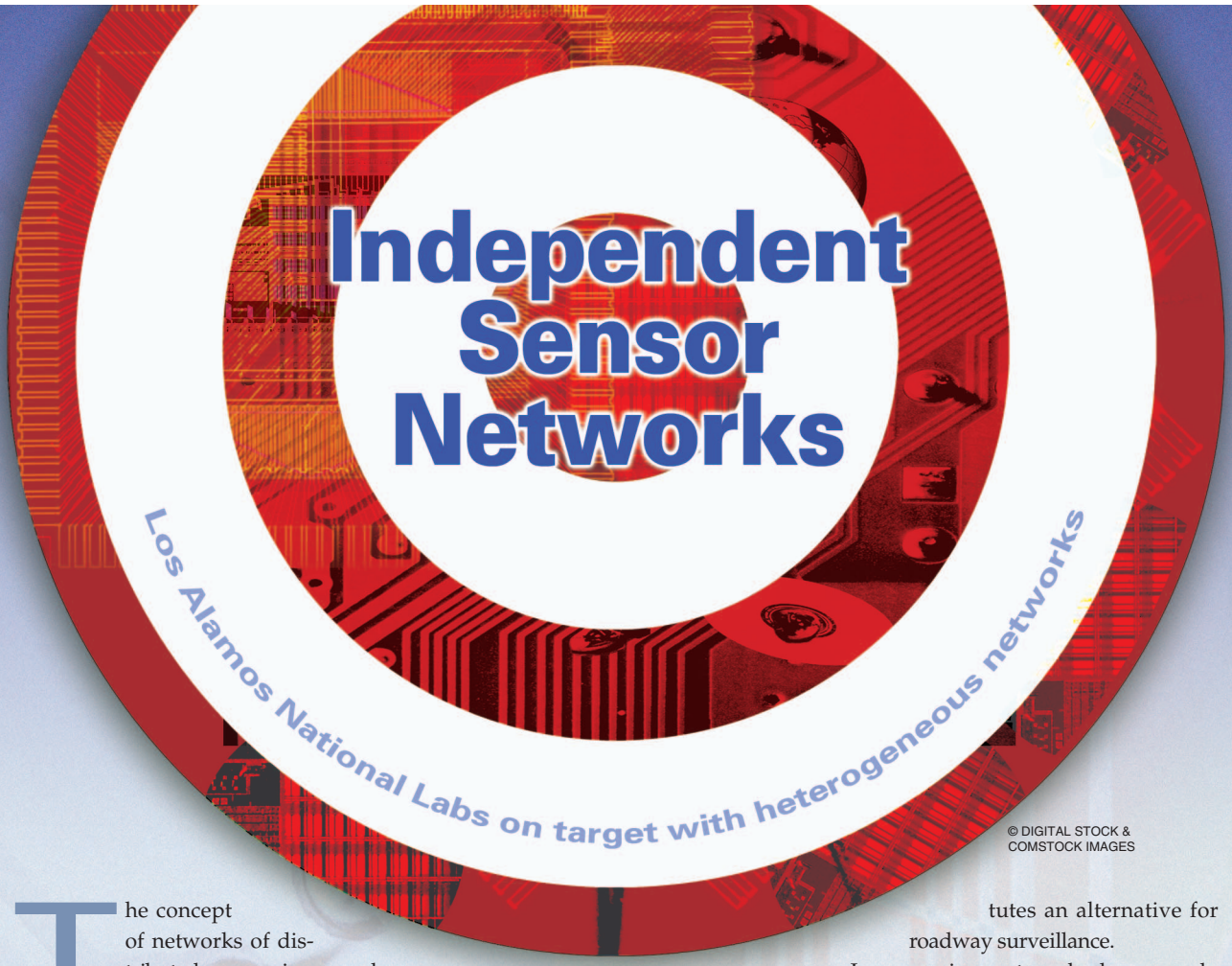

Independent Sensor Networks

Los Alamos National Labs on target with heterogeneous networks

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The concept of networks of distributed sensors is a popular topic of research. Currently, many systems focus on environmental monitoring applications. One of these is a network that gathers information about the underground burrows populated during the summer by flocks of sea birds off the coast of Maine on Great Duck Island [1]. Similarly, a wireless network has been deployed in a grove of redwoods near Sonoma, California, to compile information on the microclimates surrounding these trees [2]. Other systems focus on facility monitoring applications such as the prototype installation of Intel iMotes at its Jones Farm fabrication plant in Hillsboro, Oregon, where equipment is monitored for signs of stress [2]. All of these applications are sparked by the desire to develop a persistent knowledge of conditions in an environment where continual human presence is undesirable or impossible.

Homeland security and the potential for nuclear weapons or dirty bombs has necessitated another type of environmental monitoring, that for radioisotopes. Select traffic points in the United States may be monitored for illicit isotopes by commercially available portal minitoring systems. Although these portals are extremely useful in their application, they are large, conspicuous, costly, and require vehicles to pass through them at low speeds. In contrast, an equally effective network of small, inexpensive, and less efficient radiation detectors constitutes an alternative for roadway surveillance.

Inexpensive networks have made many recent advances because they benefited from the commercial development of inexpensive wireless sensor network products from companies such as Crossbow Technology and Dust Networks. Although these systems have demonstrated the utility of continuous monitoring using small, low-cost, low-power devices, the requirements of many other applications demand substantially more resources. Some applications, for example, rely on the real-time processing of complex signals for signatures of interest where hardware selection is based on computational capabilities rather than node size or power usage.

The focus of our research efforts at Los Alamos National Laboratory has been on the development of heterogeneous networks of small, low-power, easily concealed nodes and larger, more compute-capable nodes for in-situ data processing. These networks must be able to reconfigure themselves independently based on the data being collected across a number of sensor types in real time. We selected an application pertinent to current national and global security issues to demonstrate the relevant concepts. We are developing methods of guarding against a potential terrorist attack using a simple radiological dispersal device (RDD). In most instances, the RDD, or its components, can be transported in

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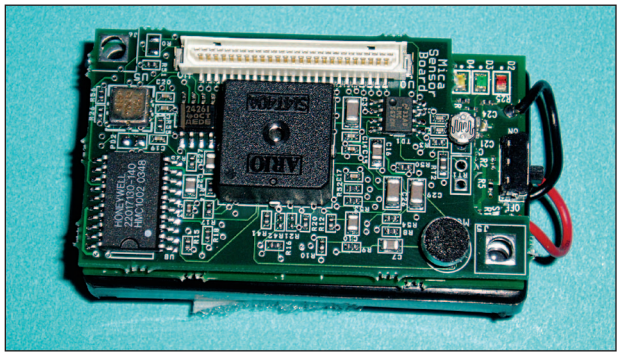

Fig. 1. The Crossbow Technology MICA2 processor/radio mote operating at 916 MHz.

a motor vehicle along a U.S. roadway to provide law enforcement an opportunity to intercept.

Simulation

System development efforts at Los Alamos are addressing implementation issues with simulation studies before moving to hardware prototyping. These studies have developed around the Distributed Sensors Simulator (DSS) v 0.8, which was completed in conjunction with the University of New Mexico and approved for open-source release by the U.S. Department of Energy (www.lanl.gov/dsn). The DSS accepts user-specified data on the sensor node locations and characteristics, as well as the physical characteristics of the sources and their motion through the sensor array, and simulates the implementation and debugging of wireless sensor networks. This simulation package helps investigators study topological, phenomenological, robustness, and scaling issues in networks of distributed sensors.

Our studies have focused on demonstrating the detection differences for roadway monitoring between a high efficiency radiation portal monitor and a network of small, inefficient radiation detectors. A portal combines a large detector cross section with a relatively long integration time to produce accurate detection of the source. An optimum network configuration exists for a particular set of detection characteristics beyond which additional array components provide no further performance improvements [3].

The radiation readings produced in a network must be coordinated with the vehicle's motion through the array to compensate for the inefficiency of the smaller, less expensive sensors. We used a coherent signal addition algorithm that allows the pertinent data to be pooled, yielding a considerably higher detection accuracy than that obtained from a single detector of the same size. In general, the length of the array is directly related to the size and type

Fig. 2. Array of MICA2 motes placed in weatherproof enclosures and field-tested on tripods.

Fig. 3. Array of MICA2 motes field-tested with ground placement along the roadway.

of the material being detected, the deployed sensors, the distance of the detectors to the source, and the speed of the vehicle though the network. Simulations have yielded positive results for arrays of various detector sizes and types [4]. Our studies indicate that arrays of detectors can provide better results than a single, high efficiency portal monitor. These results influenced our efforts for implementing the hardware.

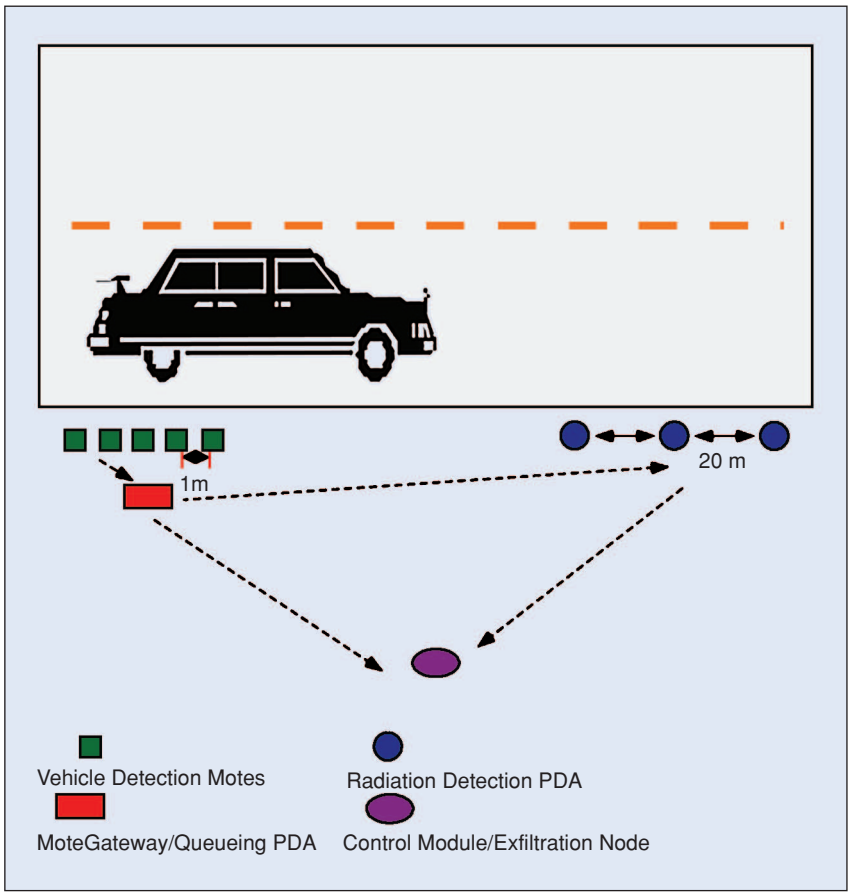

Fig. 4. System diagram of the field-tested roadway surveillance system.

Wireless Network Hardware

Our hardware integration efforts focused on commercial off-the-shelf (COTS) hardware product solutions. The goal of our work has been to implement a heterogeneous wireless network where small, low-compute, low-power sensor nodes collect data and reconfigure larger, more compute-capable nodes. When we began this work, a single COTS product was not available to provide the full solution necessary for our application. Instead, our approach combines commercial wireless mesh network nodes produced by Crossbow Technology with a PDA wireless network implementation developed at the University of New Mexico.

The Crossbow wireless mesh network comprises a backbone of the MICA2 motes shown in Figure 1. These devices employ a Chipcon CC1000 wireless radio with a center frequency of 916 MHz. This radio has 50 channels available with a data rate of 38.4 k baud, a receive sensitivity of −98 dBm, and can support a range of output power levels between −20 dBm and 10 dBm. In general, the wireless performance of the motes is dependent on the characteristics of the selected antenna. We chose an omnidirectional quarter-wave whip antenna to provide uniform coverage over a wide outdoor area. For storing measurements and data, the MICA2 motes use 16 MHz, 8-bit Atmega 128L microcontrollers with 10 b ADCs, 128 kB of program flash, and 4 MB serial flash [5], [6].

In addition to the network of Crossbow motes, we selected a network of wireless-capable PDA devices that is Linux based because of the relative maturity of the Linux operating system and its extensive user community that continues to provide significant programming tools. These devices are moderately sized and have moderate power usage with an 802.11 b capability. However, they maintain considerable data processing capabilities. The Sharp Zaurus 5600, employed in this work, is based on a 400 MHz Intel Xscale processor with 64 MB of flash plus 32 MB of SDRAM memory. Batteries power the motes and the PDA devices.

Preliminary hardware testing indicates that the MICA2 motes exhibit a 80 m (260 ft) transmission range when placed on tripods 1.2 m (4 ft) off of the ground using the 7.6 cm (3 in) quarter-wave antenna (Figure 2). This range shrank to 4.6 m

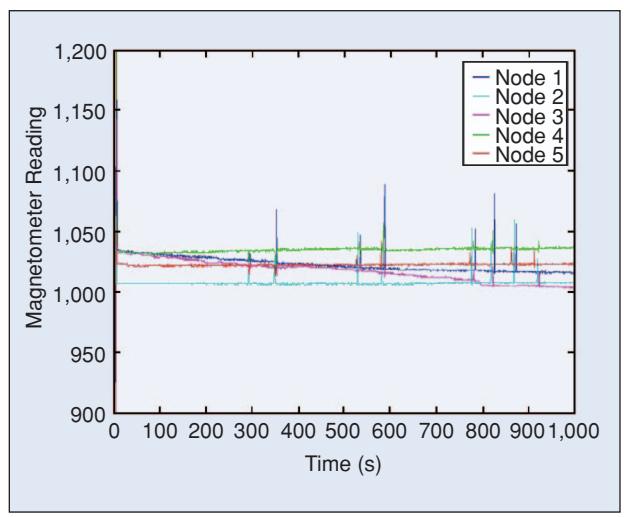

Fig. 5. Magnetometer data collected with the Crossbow MTS310 multisensor boards configured with the MICA2 motes. In this deployment, a vehicle was driven past the sensor array a total of eight times corresponding to the data spikes in the figure.

Fig. 6. Field deployment of the Crossbow mote gateway and queuing PDA.

(15 ft) when the motes were placed on the ground, as in Figure 3. These results were recorded under outdoor line-of-sight conditions using standard out-of-the-box transmission power settings. In contrast, the PDA nodes exhibit an outdoor line-of-sight transmission range of 140 m (450 ft), although at the upper limits, the actual transmission range strongly depends on the antenna positions of the transmitting and receiving nodes.

System Integration

Roadway monitoring revolves around the design of a heterogeneous network of mixed sensor types demonstrating in-situ sensing techniques. One method of reducing troublesome false alarms in the radiation detector is to analyze the data only when a vehicle is present in the network. During times of inactivity, the background radiation statistics may be continually updated. Figure 4 shows a vehicle detection subnetwork that comprises a series of five MICA2 motes with Crossbow MTS310 multisensor boards. These boards contain a microphone, a light sensor, a thermistor for temperature measurements, a two-axis MEMS accelerometer for low-performance seismic sensing, a two-axis magnetometer, and a sounder. The two-axis magnetometers are configured by the MTS310s to detect the presence of a vehicle on the roadway and to yield results such as those in Figure 5 where the data spikes correspond to vehicle presence in the network. We developed and implemented a vehicle detection algorithm on the Zaurus connected to the mote gateway shown in Figure 6. This gateway compiles the information collected by the motes, detects vehicle presence in the network, and relays the information to the radiation detection PDA network and the command-and-control console. Once cued to traffic presence, the network of three PDAs, connected to radiation detectors placed along the roadway, activate and take a snapshot reading when the vehicle is directly in front of it. The coherent signal addition techniques, used in simulation, then combine the array data to determine the presence of radioactive materials [4]. In this implementation, off-the-shelf Geiger-Mueller (GM) tube radiation detectors with 4.5 cm (1.75 in) active windows and 1.3 cm (1/2 in) length provide the source detection capabilities.

We selected the GM tube detectors because they are simple to operate, rugged, well characterized, and fairly sensitive given their low cost (approximately US$300 per unit). We fielded the Black Cat Systems GM-45 units, which have a serial output connection and are small in size (Figure 7). These units detect alpha radiation above 3 MeV, beta radiation above 50 keV, and gamma radiation above 7 keV. Cs-137, which is a radioactive source of interest in RDDs, has a gamma energy of 662 keV. By the time the radiation reaches the detector on the side of the roadway, it will be reduced to a few hundred kiloelectron volts. Although the GM-45 is an inefficient radiation detector, it can be effectively combined in an array to detect materials of interest passing on the roadway.

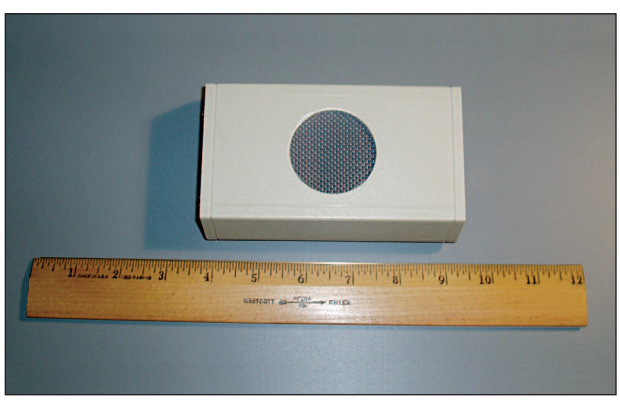

Fig. 7. Black Cat Systems GM-45 GM tube radiation detector.

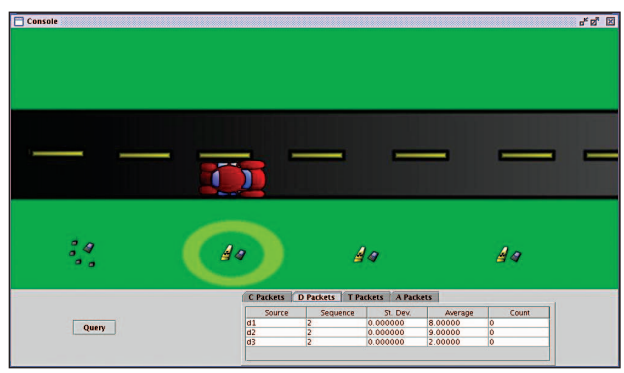

Fig. 8. Graphical interface on the command and control console displaying network messages as a vehicle passes through the radiation detection array.

Paths Forward

We have integrated and tested the network, detailed in Figure 4, here at Los Alamos National Laboratory. The MICA2 mote array detected the vehicle presence and relayed the information to the network of PDA/radiation detectors. This trigger caused the PDA/detector array to change state from background statistic collection to taking radiation snapshots with the coherent signal addition algorithms running on the PDA devices. Once the vehicle passed through the network, the PDA/detector array transitioned back to the background statistic collection mode. All state changes were logged at the command-and-control console and displayed in the graphical user interface, as shown in Figure 8. A Fujitsu ST5011 tablet PC with an 802.11 b wireless capability is the command-and-control console.

These preliminary field tests have demonstrated the detection concepts and in-situ capabilities of this system. Areas for additional research includes network communication protocols, array timing enhancements, and implementation of more powerful radiation detectors. Advances in wireless products will prompt an increase in additional application developments. For example, efforts are currently underway at Los Alamos National Laboratory to implement newly available GPS and RFID tagging sensor modules with the MICA2 and MICA2DOT Crossbow motes. Furthermore, the introduction of the Crossbow Stargate gateway provides the opportunity to transition the PDA software modules onto the more versatile gateway hardware components. These efforts will continue to explore the ever-growing list of off-the-shelf products for viability in in-situ sensing systems necessary for applications of interest in areas such as homeland security and global situational awareness.

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