Low Cost Wireless Technologies Enable New Sensor Networks

One of the exciting application areas for wireless technology is sensors. Whether monitoring biological functions inside the human body, or observing global weather patterns, sensors provide data that has proven to be valuable for scientific research as well as prediction and warning of events. Using low cost wireless technology, sensors can be more widely deployed to provide more detailed information that can save time, increase our knowledge and save lives.

Sensor Technology

Sensors range from the ordinary, like a thermometer, to the exotic, such as ground-penetrating radar. Integrated circuit electronic sensors have been developed for many applications—temperature, humidity, motion, detection of various gases, biometrics, mechanical stress and vibration, and many other important measurements. These sensors are in everyday use in stand-alone operation as well as in interconnected wired and wireless remote links and networks.

Wireless technology has been associated with sensors for many years. On or near the bridges crossing any major river you will see a UHF antenna (typically 402 MHz) pointing to a satellite that captures the measurement and relays it to the appropriate user. Similar terrestrial communications setups are used to monitor pipelines and unattended oil and gas wells. Simple consumer weather sensing devices are readily available with wireless remote operation, typically using 315 MHz OOK or BPSK modulated short range transmitters and receivers similar to those used for remote keyless entry and garage door openers.

New Technologies to Support Sensor Networks

Low cost, low power wireless transmitters and receivers have created much interest within the sensor development community. The ability to communicate with a large number of sensors without miles of wiring, and with long-term battery life, enables new uses for sensor networks that were simply not practical before.

The demands for wireless communications vary with the complexity and amount of data being transmitted, as well as the expected considerations for size and weight, availability of power (e.g., solar cells), and the required communications distance.

Currenty, there is high interest in the emerging technology of ZigBee, which promises a good combination of simplicity, cost and low power consumption with a modest data rate. Bluetooth, 802.11 WLAN, and proprietary systems are also being used in current research projects and for planned future systems.

Network Operations

The protocols for communication within a wireless sensor network are critical for efficient use of bandwidth and power resources. Two of the behaviors being explored for sensor network protocols include:

Event-triggered communications—To conserve power, a sensor and its associated transmitter/receiver do not send data unless there is a change. At extended intervals, or upon interrogation, the unit will update information to verify that it is still operational.

Ad-hoc networking—Widely-distributed networks benefit from using neighboring nodes to relay their data to a distant base station. The drawback is that the nearest units can be occupied with relaying data from distant units instead of delivering their own data. The most distant units have complex, less reliable multi-hop relay requirements that can result in fewer data reports being completed.

Many of the sensor networking issues are similar for WLAN communications, battlefield networks and other systems. Sensor networks have benefitted from existing research in these areas.

Examples of Sensor Networks

The remainder of this article will be devoted to descriptions of several sensor networks that are being implemented at a research level.

One of the most ambitious projects is Global Environmental Micro Sensors (GEMS), being developed by ENSCO, Inc. As reported in April 2005 [1], the GEMS concept features a large number of buoyant environmental sensors drifting in the atmosphere at various altitudes. The value of such an in situ planetary monitoring system is easily imagined—the data would be far more detailed than what is now being gathered by ground, balloon and satellite monitoring, enabling both real-time monitoring of weather events, as well as developing precise models of atmospheric behavior.

Some of the challenges of a system like GEMS are equally easy to imagine. To remain aloft, the final design sensors are projected to weigh no more than 5 grams, although somewhat larger units could be used in some scenarios. Because these units would be drifting in the atmosphere, they can travel well beyond the range of a ground station. Satellite links are a possibility, but the lowest power solution appears to be an ad hoc network.

A major reason for the 5 gram target mass is the requirement that they not damage an aircraft engine in the event one is sucked into the intake during flight. The units would be roughly the size of a bird, intended to comply with current guidelines for aircraft performance.

The paper reports early research with tethered balloons and currently-available off-the-shelf components. As an example of the development process, these early prototypes showed a tendency to increase in temperature due to solar heat gain as well as retained heat within the styrofoam-insulated electronics packages.

Ecological and environmental monitoring are areas of high interest for wireless sensor networks, since they would extend existing monitoring systems. The PODS research project in Hawaii [2] is a network of wireless environmental sensors, part of an investigation into the reasons why an endangered plant species will grow in a particular area, but not in neighboring areas. The system uses camouflaged modules (Pods) with a computer, radio transceiver and environmental sensors. Some of the Pods also include a high resolution digital camera. The data is relayed via wireless link to an Internet-connected hub.

The PODS project uses both Bluetooth and IEEE 802.11 operating systems. Power conservation is accomplished by collecting enviromental data in ten minute intervals, with photos collected once per hour.

A different type of environmental monitoring network is CORIE [3], a pilot environmental observation and forecasting system (EOFS) for the Columbia River. It integrates a real-time sensor network of 13 stationary sensor nodes, plus one floating sensor station that drifts off shore. The fixed nodes are powered from the electric grid, while the floating node is powered from a solar panel and batteries.

One goal of the project is to characterize and predict complex circulation and mixing processes in the system comprising the lower river, the estuary and the near-ocean. Early applications of CORIE have also addressed the issues of salmon habitat and passage, hydropower management, navigation improvements and habitat restoration. CORIE is an important test bed for both sensor technology and cooperative reseach among many participants. The importance of the Columbia River system to the economy and ecology of the region has generated support and interest from numerous academic, governmental and environmental researchers.

Medical sensors are another area of high interest. Autonomous implantable sensors are much safer than those with wired connections that penetrate the skin. Various frequencies have low absorption by body mass and fluids, requiring the least power for radio communication and minimizing the potential for biological effects due to RF radiation. A recent paper [4] described the technical issues faced by designers of implantable sensors. The authors describe the development of a fully-integrated CMOS transceiver for use in the 402 to 405 MHz allocated to Medical Implant Communication Systems (MICS) by the FCC.

The first major issue noted is that biomedical signals are low bandwidth and low amplitude. The sensor and its radio link must operate for long enough duration to capture these signals, and its own operation must not mask, or interfere with, the detection of those signals. To achieve these goals, as well as those for low power consumption, the researchers used a direct-conversion receiver architecture and simple FSK modulation. The required receiver sensitivity, calculated by ordinary path loss parameters plus the additional loss through tissues, was determined to be –91 dBm (26 dB noise figure). This level of performance is easily achievable at this frequency, using a CMOS RF process.

The core of the transceiver is a direct-modulated VCO, which is shared by both transmitter and receiver. To obtain the required quadrature LO signals for the direct-conversion receiver, the designers used a ring oscillator. This topology delivers the desired I and Q signals without the additional complexity of a phase shifter or frequency divider circuitry. Ring oscillators are not particulary well-behaved with regard to process variations and phase noise. A PLL with an additional calibration loop was used to alleviate these difficulties.

Wireless Sensing (Not Just Communications)

The subject of wireless technology in the sensors themselves is sufficiently extensive for coverage in a future article. Among wireless technologies, radar is by far the most common remote sensing method, with much work underway on portable, vehicular, aviation and space-borne systems.

Examples include a satellite-based system that measures precipitation directly, greatly increasing the observation and recording of rainfall amounts in remote areas. Aerial ground-mapping radar that can penetrate the overlying rain forest has been used for several years to obtain accurate terrain maps in remote equatorial regions. Finally, one of the earliest applications for the new technology of ultra wideband (UWB) is a radar system capable of penetrating ground and buildings.

References

1. Mark L. Adams and John Manobianco, “Mobile Ad hoc Networks for In Situ Atmospheric Sensing,” *Conference Proceedings, 2005 IEEE Wireless and Microwave Conference*.

2. Edoardo Biagioni and Kent Bridges, “The application of remote sensor technology to assist the recovery of rare and endangered species,” *International Journal of High Performance Computing Applications, Special Issue on Distributed Sensor Networks*, August 2002.

3. http://www.ccalmr.ogi.edu/CORIE/

4. Ahmet Tekin, Mehmet R. Yuce, Wentai Liu, “A Low Power MICS Band Transceiver Architecture for Implantable Devices,” *Conference Proceedings, 2005 IEEE Wireless and Microwave Conference*.