Wireless Sensor Networks Expand the Reach of Wireless Technology

Want to learn more about how design engineers are addressing the challenges of Wireless Sensor Networks? Read on!

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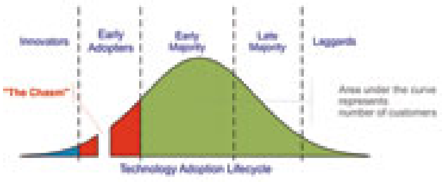

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Figure 1. Technology adoption lifecycle from Crossing the Chasm, Geoffrey A. Moore.

Every day, smart devices are collecting more and more data from the world around us. Wireless technology continues to grow to meet an increasing demand for data, and it delivers a more efficient, more flexible solution with lower installation costs. The third wave of wireless adoption, which is currently under way, provides devices beyond the laptop access to the network. Today, devices such as smart phones and wireless sensor networks (WSNs) are expanding the reach of wireless technology. At National Instruments, we are seeing more and more engineers and scientists begin to take advantage of the benefits of wireless technology for measurement applications.

In light of increasing demand, wireless design engineers face several challenges to meet the unique needs of these wireless applications, particularly with wireless sensor networks. The first challenge design engineers face is the need for low-power, battery-driven operation of WSN nodes. In remote applications, end users require a battery life of two to three years to reduce maintenance, so design engineers must create efficient power circuitry and intelligent node firmware to handle the node sleep cycle. Another application challenge is the need for long distance and reliable wireless communication. As in any monitoring or measurement system, the data and its reliability are of paramount importance. Moreover, most WSN deployments cover a large area and must be able to efficiently communicate within the network without losing data or disconnecting. A third difficulty that design engineers face is creating products that can stand up to the challenging environmental conditions of outdoor or hazardous deployments. WSN devices need to be designed and tested to operate and maintain measurement accuracy across broad temperature ranges and non-ideal environmental conditions.

What are the Current Trends for Wireless Technology?

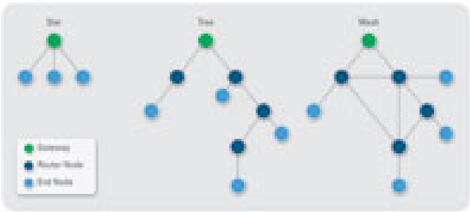

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Figure 2. Wireless network topologies.

Recently we have seen three major waves of adoption for wireless technology. The first wave of adoption began with commercial applications such as wireless bar code scanners and inventory management systems in large retail stores. The second wave was the integration of Wi-Fi into the fast-growing laptop PC market, which drove the deployment of Wi-Fi networks and made it possible to access wireless Internet in homes and public locations around the world.

The third wave of wireless adoption, which is currently under way, provides other devices beyond the laptop access to the network. Today, devices such as smart phones and wireless sensor networks are expanding the reach of wireless. For National Instruments, wireless technology has matured to a point where engineers and scientists can begin to take advantage of the benefits of wireless technology for measurement applications.

Are Wireless Sensor Networks Ready for Mainstream Monitoring Applications?

In his book Crossing the Chasm, Geoffrey A. Moore introduced the technology adoption lifecycle. This curve highlights a chasm that exists between visionaries who are early adopters of technology and pragmatists who wait for proven technologies and products. For technologies to "cross the chasm" they must have products with defined specifications and system deployment guidelines.

Wireless sensor networks (WSNs) are an emerging technology that have reached a critical point in the technology adoption lifecycle where the success of innovators and early adopters combined with products from proven vendors will allow end users to address challenging deployments. Specific applications, such as environmental monitoring, building automation, and health care, are also contributing to the adoption of wireless sensor networks.

In addition to hardware products from proven vendors and defined applications that are driving adoption, WSN designers and end users also need a software model in place to support hybrid wired and wireless systems. Familiar graphical software design tools like NI LabVIEW are ideal for wireless system configuration and deployment in addition to the acquisition, storage, and analysis of wireless measurement data. With these types of open software tools, customers can combine wired and wireless measurement systems, connect to third-party wireless measurements and WSN networks from a wide range of vendors, and even deploy graphical programs to NI WSN nodes to customize their behavior.

What Application Challenges do Design Engineers have to Address with WSN Products?

The first challenge design engineers face is the need for low-power, battery-driven operation of WSN nodes. In most applications, end users require a battery life of two to three years for remote deployments, so design engineers must create efficient power circuitry and intelligent node firmware to handle the node sleep cycle.

The second application challenge is the need for long-distance and reliable wireless communication. As in any monitoring or measurement system, the data and its reliability are of paramount importance. Moreover, most WSN deployments cover a large area and must be able to efficiently communicate within the network without losing data or disconnecting.

A third difficulty that design engineers face is creating products that can stand up to the challenging environmental conditions of outdoor or hazardous deployments. WSN devices need to be able to operate across broad temperature ranges and non-ideal environmental conditions, and conform to standard regulatory certifications.

How are Design Engineers Addressing the Need for Low-power, Battery-driven Devices?

The first design consideration involves a power-efficient circuit design. Designing for minimal peak/average current draw is critical. Design engineers should choose transistor components with a minimal ON resistance and configure currents and effective load resistances to ensure that they are operating in the proper region of the power hyperbola.

When choosing a processor for a WSN node, a designer should pay close attention to the active and sleep current specifications, as the processor and radio can be the most power-hungry components in a WSN device. This brings us to another critical design consideration: intelligent firmware that can manage node sleep cycles and heartbeat intervals. Sometimes node software can play a larger role in power consumption than the hardware components.

In most WSN systems, end nodes are in a low-power sleep state for the majority of operation, waking up only to take and send measurements or transmit "housekeeping" information such as configuration data, routing tables, or link quality. The firmware must be designed so that the processor and radio are asleep or off as much as possible, limiting the amount of overall power consumption. Moreover, when the node wakes up to sample and transmit, data must be encoded in such a way to minimize transmission times. The firmware should also elegantly handle communication from the base station or gateway so that messages or configuration information is sent when a node is awake to receive it. Since the node is mostly asleep, there must be strict timing and coordination algorithms so that node-to-node and node-to-gateway communication channels are maintained.

In addition to the node firmware, designers can also take advantage of customizable node intelligence, such as the ability to wirelessly download and run LabVIEW code on NI WSN nodes. The NI LabVIEW Wireless Sensor Network (WSN) Module can be used to improve battery life by modifying how many channels the node samples and how often the node samples those channels and transmits the data. By powering off parts of the analog front end or transmitting only meaningful data (such as data above a threshold), NI WSN nodes can be optimized for longer battery life.

How are design engineers addressing the need for reliable and long-distance application

requirements?

When designing any wireless device, one of the first choices a designer must make is which wireless protocol to use for wireless communication. There are several popular choices today, including variants of IEEE 802.11 and 802.15.4. While these protocols define the physical and data link layers, they typically do not define the network layer, which is where a wireless network can achieve increased distance and reliability. Therefore, design engineers must write their own custom software to complete the protocol stack or rely on existing stacks provided by vendors such as Digi or Texas Instruments.

When implementing the network layer of the protocol stack, network topology support becomes a critical criterion because network topology and the tradeoffs between distance and reliability are closely linked. There are several network topologies that are in use today, each varying in complexity and features. When it comes to wireless sensor networks, three topologies are most widely used.

The first, and most basic, is the star topology, in which each node maintains a single, direct communication path with the gateway. This topology is easier to program and architect, but it restricts the overall distance that your network can achieve and does not provide any inherent redundancy to provide reliability. The maximum distance of a star topology is dictated by the maximum single-hop range of the wireless radio and communication protocol. The design and adoption of wireless sensor networks depends on their ability to extend past a simple star topology.

To increase the distance a network can cover, you can implement a cluster, or tree, topology. In this more complex architecture, each node still maintains a single communication path to the gateway but can use other nodes to route its data along that path. This topology suffers from a problem, however. While you increase the total distance your network can cover, it fails to increase the reliability; if a router node goes down, all the nodes that depend on that router node also lose their communication paths to the gateway.

The topology that addresses both distance and reliability is the mesh network topology. Like the cluster topology, router nodes can be used to increase network range by implementing hops. But in a mesh network, which is self-healing by design, nodes can maintain multiple, redundant communication paths back to the gateway. Therefore, if one router node goes down, the network automatically reroutes the data through a different path. The mesh topology, while very reliable, does suffer from an increase in network latency because data must make multiple hops before arriving at the gateway.

From a design perspective, many engineers are choosing IEEE 802.15.4-based protocols like ZigBee because they are low power and support self-healing mesh networks. In IEEE 802.11-based schemes, like Wi-Fi, devices are usually limited to star or cluster topologies. When it comes to mesh networks, there are also tradeoffs between powered meshing and battery-powered meshing. We already discussed the importance of power-efficient hardware and software designs, but in order to take advantage of battery-controlled devices, designers have to choose between true battery-powered meshing, or mesh routing in which router nodes must be externally powered.

How are design engineers addressing environmental challenges of outdoor deployments?

When addressing the environmental challenges of outdoor deployments, designers must first choose hardware components that can withstand the various environmental conditions. This includes choosing components with industrial temperature ratings and designing mechanical enclosures and electrical PCBs to meet extended shock and vibration requirements. Designers should also take care when creating the analog front end of the device, as measurement accuracy can vary across wide temperature ranges depending on the circuit design. After initial product revisions, designers also need to test their products according to varying requirements. This includes temperature, shock, and vibe ratings, as well as other standards such as Ingress Protection.

While not specific to designers, the appropriate installation and deployment of WSN devices is also important in addressing this concern. End users must be sure to use adequately rated enclosures or other housings to protect the devices from environmental influence, while at the same time preserving measurement accuracy. Sensors, power supplies, and especially batteries must be chosen carefully so as to function properly across the environmental conditions of the application.

How will wireless technologies evolve in the next two to five years?

The first trend is a convergence of wireless protocols used in low-power WSNs. Currently most designers choose a protocol independent of the market. As more customers adopt WSNs, the marketplace will require better integration with existing standards like the Internet Protocol (IP) to support further integration with existing networking infrastructure.

The second trend is an increase in the processing capabilities of WSN nodes in terms of CPU performance and local storage. The short-term trade-off with this performance increase will be increased power requirements that may shorten operational battery life.

An advance in power management and energy harvesting technologies (to offset the increased power requirements) is the third trend that is developing. NI is monitoring new energy harvesting technologies, more efficient power storage technologies, and power management improvements. As these technologies continue to improve, they should offset the increases in power requirements. The end result for customers is increased performance with similar operating lifetimes and a convergence of standards to support interoperability.

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