Implementing ZigBee wireless mesh networking

ZigBee offers unique advantages for wireless applications. But with a technology this new, realizing a successful ZigBee implementation requires understanding its architecture and operation, assessing design options at the chip and module level, and weighing practical considerations relative to specific application needs.

By Tim Cutler

ZigBee is the product of the ZigBee Alliance, an organization of manufacturers dedicated to developing a networking technology for small, ISM-band radios that could welcome even the simplest industrial and home end devices into wireless connectivity. The ZigBee specification was finalized in December 2004, and products supporting the ZigBee standard are just now beginning to enter the market.

ZigBee is designed as a low-cost, low-power, low-data rate wireless mesh technology. The ZigBee specification identifies three kinds of devices that incorporate ZigBee radios, with all three found in a typical ZigBee network (Figure 1):

- A coordinator, which organizes the network and maintains routing tables.
- Routers, which can talk to the coordinator, to other routers and to reduced-function end devices.
- Reduced-function end devices, which can talk to the coordinator, to other routers and to reduced-function end devices.

To minimize power consumption and promote long battery life in battery-powered devices, end devices can spend most of their time asleep, waking up only when they need to communicate and then going immediately back to sleep. ZigBee envisions that routers and the coordinator will be mains-powered and will not go to sleep.

To illustrate how these components inter-relate, consider ZigBee networking in office lighting. Several manufacturers are currently developing inexpensive sensors for fluorescent tubes that let lights be turned on and off by battery-powered wall switches, with no wires between switch and fixture. The light switch is the end device, powered by a button cell battery that will last for years; the switch wakes up and uses battery power only when flipped on or off to transmit the new state to the fluorescent tubes’ routers. The routers are already connected to the mains and are not concerned with battery conservation. Any one of the fluorescent tubes can contain the coordinator. The implications are enormous for new office construction—no more electrical cable runs for lighting and the ability to reconfigure lighting controls at almost zero cost.

ZigBee extends similar benefits to a wide range of industrial automation and control applications.

ZigBee benefits

In all of its uses, ZigBee offers four inherent, beneficial characteristics:

- **Low cost.** The typical ZigBee radio is cost-effective. Chipset prices can be as low as $12 each in quantities as few as 100 pieces. While the 802.15.4 and ZigBee stacks are typically included in this cost, crystals and other discrete components are not; design-in modules fall in the neighborhood of $25 in similar quantities. This pricing provides an economic justification for extending wireless networking to even the simplest of devices.
- **Range and obstruction issues avoidance.** ZigBee routers double as input devices and repeaters to create a form of mesh network. If two network points are unable to communicate as intended, transmission is dynamically routed from the blocked node to a router with a clear path to the data’s destination. This happens automatically, so that communications continue even when a link fails unexpectedly.
- **Security.** The use of low-cost routers can also extend the network’s effective reach. When the distance between the base station and a remote node exceeds the devices’ range, an intermediate node or nodes can relay transmission, eliminating the need for separate repeaters (Figure 2).
- **Multisource products.** As an open standard, ZigBee provides customers with the ability to choose vendors as needed. ZigBee Alliance working groups define interoperability profiles which to ZigBee-certified devices must adhere. A ZigBee-certified radio will interoperate with any other ZigBee-certified radio adhering to the same profile. This promotes compatibility and competition, which allows the end users to choose the best device for each particular network node, regardless of manufacturer.

ZigBee architecture

For purposes of this discussion, three areas of architectural responsibility are in a ZigBee engineering effort (Figure 3):

- The physical and MAC layers take full advantage of the physical radio specified by IEEE 802.15.4. The 802.15.4 specification describes a peer-to-peer radio using direct-sequence, spread spectrum (DSSS). The specification also calls out the data rates, channelization and modulation techniques to be employed.
- The ZigBee Alliance specifies the logical network, security and application software, which are implemented in a firmware stack. It is the ZigBee networking stack that creates

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**Figure 1.** ZigBee network incorporates coordinators, routers and reduced-function end devices in a variety of topologies (mesh topology shown).
the mesh networking capability. Each microcontroller/RF chip combination requires its own ZigBee stack due to the differences in microcontrollers and RF chips. Typically, the ZigBee stack is included with either the microcontroller or RF chip. The stack may belong to the chip vendor, be provided by the chip vendor from a third-party source, or be provided by a third-party source for a specific microcontroller/RF chip combination.

The application layer is defined by profiles, of which there are two types: public profiles are those certified by the ZigBee Alliance for interoperability purposes, and private profiles are for use in closed systems.

A word about the ZigBee Alliance: The following discussion includes options that require access to intellectual property available only to members of the ZigBee Alliance. There are three types of membership; all companies that plan to release products incorporating ZigBee technology must become at least adopting members, an entry-level membership that provides such benefits as access to specifications and developer conferences/workshops. For information, visit www.zigbee.org.

ZigBee implementation: hardware, firmware considerations

Members of the ZigBee Alliance offer ZigBee-compliant platforms in either the chipsets themselves or design-in modules developed on them. There are three basic options for ZigBee hardware implementation:

- **Chipset reference designs.** ZigBee chipmakers offer reference designs for their chipsets, and, to be relevant for as many different applications as possible, reference designs are broad. Using a reference design may mean giving up real estate and incurring cost for capabilities you don’t need, but you’ll avoid the time and expense of a custom design.

- **Chipset custom designs.** You can save space and recurring product expense by building a custom design around a chipset. Be sure to work with a chipset you know well. Because current sets all consist of an RF chip paired with a microchip, you’ll need both RF and digital design engineering capability.

- **Design-in modules.** A number of OEM module manufacturers’ products incorporate ZigBee-compliant chipsets. With any module solution, the RF work is already complete, often with optimization for particular types of applications and typically including FCC and ETSI certification as a module. You may or may not find a module that supports your application in the optimum manner, but if you do, you’ll get to market quickly and greatly reduce development costs. Because module manufacturers aggregate demand from a number of customers, they often will be building modules in such large quantities that the price of a module may even be less than the cost of a chipset solution.

ZigBee implementation: profile considerations

The chipset and the stack are incomplete without a profile, which defines the module application. As mentioned previously, there are public profiles and private profiles. For public profiles, ZigBee Logo Certification is available; private profiles are not intended to interoperate and, therefore, cannot be certified.

At this point, the simple fact is that there is only one ZigBee public profile, and that’s for lighting. If you are developing a ZigBee solution for any other type of application and can’t wait for the development of an appropriate public profile, you’ll need to go with one of the private profiles that have been developed or develop your own.

Some chipmakers have created private profiles that are integrated into their stacks, typically general-purpose serial UARTs. Module manufacturers are more likely to have produced application-specific private profiles and may offer something suitable to your needs.

Implementing profiles, either public or private, is no small undertaking. In addition to the need to license development tools from the stack providers and attending a training class, be prepared to spend a fair amount of time studying the various firmware components that constitute the ZigBee stack. Also make sure that your firmware engineers are familiar with the microcontroller used in the platform. While none of these items is insurmountable, they do add to development costs and time to market.

If the decision is made to use a third-party ZigBee module, you can still develop your own profile. Most module manufacturers can provide the hardware abstraction libraries, which reduce the effort to create your own profile. Some module manufacturers offer services to create a custom profile for their customers. While this is not a free service, it can simplify the development effort and shorten time to market.

A word about profiles and gateways: While every ZigBee network needs a coordinator, not all need a gateway. In the lighting example, the ZigBee network doesn’t need to interface to another network. For most sensing and monitoring applications (and many other industrial/commercial applications), the ZigBee network will need to interface to another network, either Modbus or Ethernet. When that’s the case, you’ll want to make sure that your solution is available with a compatible gateway that implements the same profile.

ZigBee implementation: certification, testing

Once you have engineered your product with the necessary hardware, firmware and profile, it’s now time to start testing. First there are the FCC and ETSI tests. Then there are the ZigBee tests. But before you can run these tests, you must join the ZigBee Alliance. By joining the ZigBee Alliance you gain access to the IP embodied in the ZigBee technology. Without joining the alliance, your legal ability to use the ZigBee technology can be called into question.

To market products based on the ZigBee technology, one of two testing levels must be passed. The first level is referred to as ZigBee-Friendly and the second level is ZigBee-Logo Certified. Both levels of testing require that the ZigBee-Compliant Platform testing be successfully completed first. While
some of the testing requirements are being finalized at the time of this writing, the general intent behind the testing is well established.

ZigBee-Compliant Platform (ZCP) testing may be completed by a chipset manufacturer or a module manufacturer and passed through to their customers. This testing is concerned primarily with compliance testing at the stack profile (different from the application profiles). As long as the ZigBee implementation uses the stack profile used for the ZCP testing, it does not need to be repeated. If, however, a different stack profile is needed for your device and that stack profile was not tested by the chipset or module manufacturer, you will need to repeat the ZCP tests.

ZigBee-Friendly testing is concerned with products that implement private profiles to ensure they do not cause problems with other ZigBee networks that may be nearby. This could come about due to the amount of time a device transmits, etc. If a chipset or module manufacturer has passed the ZigBee-Friendly testing, a product incorporating the device does not need to be retested as long as the profile used in the testing is used unchanged. If any changes are made to the profile, the product with the modified profile must be submitted for ZigBee-Friendly testing. Note that module configuration settings are not considered changes to the profile.

ZigBee Logo Certification is testing performed on a ZigBee-Compliant platform using a public profile. This testing is concerned with interoperability with other device manufacturers’ products and is the highest level of testing. Once this testing has been passed, the product may carry the ZigBee logo along with the icon relating to the application profile (home control/lighting for example). A bit of a catch-22 with this testing is there must be at least three vendors with products implementing the application profile. When a profile is made public, none of the vendors can get ZigBee Logo Certification until there are three vendors that have implemented the profile.

### Summing it up: choosing the best options for you

In the end, decisions regarding ZigBee hardware/firmware, profiles and certifications depend on practical decision points that must balance what you want of your product with what’s available today.

- **Ultimate control over product details** is achievable with a custom design around a ZigBee-compliant chipset. This method carries high up-front costs in RF and digital engineering, plus investments in test equipment and test fees, and will typically encounter the longest time to market. It may also yield the lowest recurring per-unit cost; if manufacturing quantities are sufficiently high and if time to market is not critical, this is an advantageous method.

- **The use of a chipset reference design** will provide faster time to market, eliminating much of the engineering cycle of a custom design. This option still incurs costs in development, test equipment and testing, and will likely mean a higher recurring per-unit cost than a custom design due to the broad nature of reference designs. But if time to market is important and if projected manufacturing quantities are sufficiently high, this is a good choice.

- **The use of a design-in module** will generally provide the shortest time to market and the lowest up-front cost. It may represent the most economical choice, especially if manufacturing quantities are modest or uncertain. If you can locate a module with a profile that meets your needs, you’ll have smooth sailing—in this case, you’ll avoid not only much of the engineering costs, but the investment in test equipment and test fees as well.

There are many specifics to be considered among the product resources available to you, and they and the dynamics that govern engineering choices will change as the ZigBee standard matures. To help make the best-informed decisions, you are encouraged to visit www.zigbee.org for further discovery.

### ABOUT THE AUTHOR

Tim Cutler is vice president of marketing and OEM/industrial sales at Cirronet, Inc. in Atlanta, Ga. In addition to extensive experience in executive sales and marketing roles and an MBA degree, Cutler holds a degree in electrical engineering from the Georgia Institute of Technology and two patents for microprocessor-based design. He can be reached at tcutler@cirronet.com.