DaintreeNetworks

What's so good about mesh networks?

Abstract

This paper provides an overview of the available IEEE 802.15.4™ and ZigBee™ network topologies, with a summary of the benefits for each one. It then delves into the mesh topology in detail, describing its benefits, strengths, and applications.

Introduction

IEEE 802.15.4 and ZigBee are standards-based protocols that provide the network infrastructure required for wireless sensor network applications. 802.15.4 itself defines the physical and MAC layers, whereas ZigBee defines the network and application layers.

For sensor network applications, key design requirements revolve around long battery life, low cost, small footprint, and mesh-networking to support communication between large numbers of devices in an interoperable and multi-application environment. These have driven the specifications for 802.15.4 and ZigBee to deliver a simple yet relatively resilient, large-scale, multi-hop wireless network with the ability to support many different applications in an interoperable and scalable way.

This whitepaper provides an overview of the 802.15.4 and ZigBee network topologies. It then explores the benefits and applications for mesh networks, and explains why this network type is ideally suited to wireless sensor and control networks.

How networks are formed

The life of a ZigBee network begins with network formation. This starts when a router uses energy scans to identify a channel that is relatively free of interference, and then sets itself up to be the network coordinator.

Subsequent to this, devices that wish to join the network will do so by first issuing beacon requests to solicit beacons from devices that could potentially host them on the network. Initially, only the coordinator will respond. In addition to the coordinator, any device capable of allowing other devices to join the network is referred to as a ZigBee router. What ensues is a series of message exchanges that will determine whether a device may join the network. In ZigBee, this process is called association. A key factor in such a determination is a router's capacity to accept additional devices as its child.

Where 802.15.4/ZigBee differs from other wireless technologies, such as 802.11/Wi-Fi, is in permitting a hierarchy of associations rather than a single parent-child structure. For instance, a device joining the coordinator could itself be a router, and that device could permit other devices to join it. As a result, multiple levels of associations can be achieved.

Supported network topologies

"Topology" refers to the configuration of the hardware components and how the data is transmitted through that configuration. 802.15.4 and ZigBee support three different network topologies: star, mesh, and cluster tree (also called star-mesh hybrid).

The cluster tree topology is less efficient than the other two, and is therefore rarely (if ever) implemented. It is not covered in this whitepaper.

Before describing the star and mesh topologies, it helps to first understand the different types of devices these networks can include.

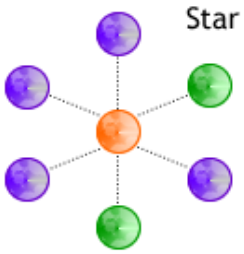
Coordinator
This device sets up the network and acts as a portal to monitor network performance and configure parameters.

Routers
These devices, also called FFDs (full function devices), extend network area coverage, dynamically route around obstacles, and provide backup routes in case of network congestion or device failure. They can connect to the coordinator and other routers, and can also have child devices.

End devices

These devices, also called RFDs (Reduced function devices), can start or receive a message, but cannot forward messages upstream or downstream. They must be connected to either the coordinator or a router, and do not support child devices.

Star topology



In a Star topology, also called point-to-point, all devices are within direct communication range to the coordinator, through which all messages are routed.

A device sends a message to the coordinator, which then passes it on to the destination device. Direct communication between the end devices is not supported.

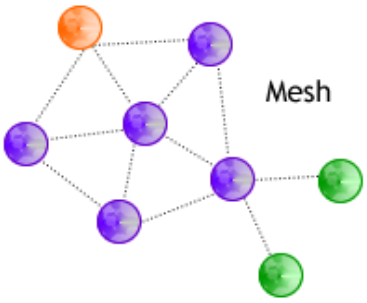
Benefits

- Its simplicity means that this topology does not require a complex network layer or routing protocols.
- Performance is generally high, with packets taking a maximum of two hops to reach their destination.

Limitations

- There are no alternative paths between the device and coordinator, so if a path becomes obstructed, communication is lost between the device and coordinator.
- The radius of the network is limited by the radio range between the coordinator and child devices (typically 30—100 meters).
- Networks must be carefully planned to ensure good connections with no obstacles or interference between the coordinator and child devices.

Mesh topology



Mesh topology, also called peer-to-peer, consists of a mesh of interconnected routers and end devices. Each router is typically connected through at least two pathways, and can relay messages for its neighbors.

Mesh topology supports "multi-hop" communications, through which data is passed by hopping from device to device using the most reliable communication links and most cost-effective path until its destination is reached.

The multi-hop ability also helps to provide fault tolerance, in that if one device fails or experiences interference, the network can reroute itself using the remaining devices.

Benefits

- This topology is highly reliable and robust. Should any individual router become inaccessible, alternative routes can be discovered and used.
- The use of intermediary devices in relaying data means that the range of the network can be significantly increased, making this topology highly scalable.
- Weak signals and dead zones can be eliminated by simply adding more routers to the network.

Limitations

- This topology has a higher communications overhead than the star topology, which can result in increased latency and lower end-to-end performance.
- Meshed routing requires more complex network protocols. This means the routers require more embedded resources, which can result in increased power consumption and costs.

The power of the mesh

Mesh networking was not created specifically for wireless sensor networks. This network topology is already hard at work in both the public switched telephone network (PSTN) and the Internet. The mesh is the best way to achieve the resiliency and scalability demanded from these mission-critical public networks.

Examining the key benefits that mesh topologies provide in a bit more detail will help to explain why it is such an appropriate choice for many wireless sensor networks.

Reliable and robust

When data reliability is key, a mesh network topology offers the best protection through its self configuring and self healing capabilities. And the redundant paths of mesh networks ensure alternative data paths and no single point of failure.

- The network is self healing, with connections between devices being dynamically updated and optimized in difficult conditions. By ensuring that each device is connected to several others (redundancy), if one drops out of the network, its neighbors simply find another route.
- The network's self configuring capabilities identify when a device is added to the network: working out what type of device it is (router or end), where its neighbors are, and what the best path is through the network. After the device's initial configuration, it continuously polls its neighbors and recomputes the best path based on signal strength and bit errors.
- If required, link quality and reliability can be increased simply by reducing the distance between wireless devices: either by moving existing devices or by adding additional ones.
- Because mesh networks use low power transmissions to reach only nearby devices, there is less interference with radio signals from other devices.

Flexible and scalable

Wireless mesh networks afford unparalleled flexibility and simplicity, and are ideally suited for applications where devices are scattered. Reality rarely comes as star, ring, or a straight line. In difficult environments where not every device can communicate directly with the coordinator, chances are that they can communicate with one or more of their neighboring devices.

- Mesh network routing offers great flexibility by permitting path formation from any source device to any destination device within the network.
- You can extend distance, add redundancy, and improve link quality and the general reliability of a mesh network simply by adding devices.
- Adding a new devices or relocating an existing device is as simple as plugging it in and turning it on. The mesh network automatically discovers the new or relocated device and automatically incorporates it into the network.
- Because of their flexibility and redundancy, mesh networks are extremely scalable, with the ability to support thousands of individual devices.
- Administrators can add, move, and remove devices as required without elaborate site surveys. The self-managing capabilities help to make wireless mesh networks as close to plug-and-play as any other topology ever has been—or may ever be.

Cost effective

In addition to savings through reliability and low power consumption, mesh networks provide the a number of cost benefits.

- The self configuring capabilities mean that a network can perform some tasks with minimal or no human intervention, including routing messages, adding and removing devices, and changing details for relocated devices. When routing a message, the network automatically works out the lowest cost route that avoids any problem areas.

- The redundancy and self healing capabilities provide for less downtime, with messages continuing to be delivered even when paths are blocked or broken.
- The self-configuring, self-tuning, self-healing, and self-monitoring capabilities of mesh can help to reduce the management burden for system administrators.
- Advanced mesh networking protocols coordinate the network so that nodes can go into sleep mode while inactive and then synchronize quickly for sending, receiving, and forwarding messages. This ability provides greatly extended battery life.
- A mesh network can be deliberately "over-provisioned" simply by adding extra devices, so that each device has two or more paths for sending data. This is a much simpler and less expensive way of obtaining redundancy than is possible in most other types of networks.
- Compared to the cost of point-to-point copper wiring and conduit required for traditional wired networks, wireless mesh networks are typically much less expensive. The self-management capabilities of mesh network can also help to make installation less expensive than traditional wireless systems.

Typical applications

There are numerous applications in which the redundant, self configuring and self healing capabilities of wireless mesh network makes them the ideal solution.

- In an existing environment that is not already wired, a mesh topology provides the most flexible type of wireless network.
- At times where the network is only required as a temporary measure, the low cost and flexibility of mesh makes it an ideal wireless solution.
- When low maintenance costs are a key concern, the self configuring and self healing capabilities of mesh networking combined with its low power usage provide a very affordable solution.

Home Control

Low-power and low data rate mesh networks provide an affordable and flexible solution for home automation to monitor and control things like security, lighting, and HVAC (heating, ventilating, and air conditioning).

Networked devices in the home can include the following:

- Light switches and lights
- HVAC controls and thermostats
- Computers, TVs, and other electronic devices
- Smoke detectors and other safety equipment
- Alarm panels, motion sensors, and other security devices
- Electricity, water, and gas meters

Applications

- Enjoy flexible management of lighting, heating and cooling systems from anywhere in the home.
- Automate control of multiple home systems to improve conservation, convenience and safety.
- Configure and run multiple systems from a single remote control.

Savings

- Capture highly detailed electric, water and gas utility usage data.
- Embed intelligence to optimize consumption of natural resources. For example, automatically turn off HVAC devices and lights when the house alarm is armed, and automatically turn them back on again when the alarm is deactivated.
- Install, upgrade and network home control system without the expense and complexity of wiring.

Security

- Easily install wireless sensors to monitor a wide variety of conditions.
- Receive automatic notification (e.g. by SMS) upon detection of unusual events.

Building Automation

Wireless sensing and control mesh networks can make building automation easier and more efficient by combining lighting, HVAC, security, safety systems, and other monitoring networks into a single platform.

Applications

- Integrate and centralize management of lighting, heating, cooling, and security.
- Automate control of multiple systems to improve conservation, flexibility, and security.

Savings

- Reduce energy expenses through optimized HVAC management. For example, in a hotel, motion sensors can identify which rooms are occupied, and the network can automatically turn off HVAC devices and lights in empty rooms.
- Allocate utility costs equitably based on actual consumption.
- Reconfigure lighting systems quickly to create adaptable workspaces.
- Extend and upgrade building infrastructure with minimal effort.

Safety and Security

- Network and integrate data from multiple access control points.
- Deploy wireless monitoring networks to enhance perimeter protection.

Industrial plant monitoring (IPM)

Wireless sensing and control mesh networks provide accurate and efficient IPM, and are also ideal to deploy in hazardous environments in which you want to minimize human exposure.

Applications

- Extend existing manufacturing and process control systems reliably.
- Improve asset management by continuously monitoring critical equipment.

Savings

- Identify inefficient operation or poorly performing equipment.
- Provide detailed data to improve preventive maintenance programs. By predicting faults before they occur, failures and down-time can be reduced.
- Reduce energy and other manufacturing costs through optimized processes. For example, ensure all required components are on hand prior to the run to minimize down-time, and then monitor output to avoid costly over-runs.
- Automate data acquisition from remote sensors to reduce user intervention.

Safety and Security

- Deploy monitoring networks to enhance employee and public safety. Obtain accurate readings from pressure sensors, smoke detectors, meters, gauges, and other safety devices, and identify potential problems earlier.
- Remotely monitor hazardous areas that may previously have been as too dangerous for manual monitoring.
- Streamline data collection for improved compliance reporting.

Automated meter reading (AMR)

Flexible and scalable mesh networks provide wireless AMR, which helps to reduce effort and increase accuracy across many industries including utility companies, manufacturers, and storage facilities.

Applications

- Fast and accurate collection of meter readings.
- Provide utility company customers with the ability to monitor consumption, and also monitor and control home appliances.
- Protect goods that are sensitive to environmental conditions, such as food and pharmaceutical supplies. Quickly identify any change in conditions and automatically adjust controls to restore the required temperature and humidity levels.

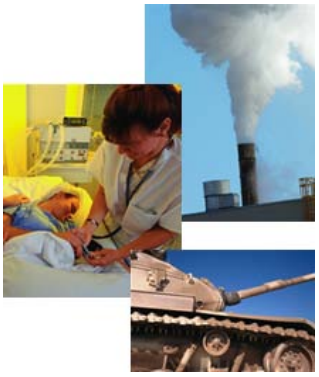
Savings

- Reduced manpower and vehicles required by utility companies and parking enforcement for meter reading.
- Protect meters from vandalism through integration with security systems.
- More accurate meter readings can lead to fewer expenses due to billing errors.

Safety and Security

- Increase public safety through accurate and timely monitoring of potential hazards such as gases or toxins, and through automated emergency procedures should any problem occur.
- Enforce restrictions placed on consumption of limited resources such as power or water. Identify any residential and commercial buildings in breach of the restrictions, and if required, reduce or disable supply to those buildings.

Other



The following list is far from exhaustive, and provides a few more examples of the ways in which low power and low data rate wireless mesh networks can be used.

Healthcare

- Within hospitals, adding patient monitors to a mesh network enables faster detection of irregularities in a patient's medical condition.
- Outside hospitals, patients can be treated at home, with doctors able to monitor their vital statistics over the Internet.
- The elderly and infirm can also be monitored at home. For example, an alert can be issued after a specified period of time if motion sensors don't detect movement or the fridge door doesn't open.

Environment and agriculture

- Emissions can be monitored and measured from installations including chemical plants, power stations, factories, and mining operations: not only for reference and potential greenhouse taxes, but also to quickly detect any hazards being released into the environment (such as gases or toxins).
- Because of its robustness and self-management capabilities, wireless mesh networks are ideally suited for outdoor agriculture and irrigation use. Sensors can monitor weather and soil conditions to control irrigation levels.

Defense and national security

- Mesh networks can be used to monitor and protect installations that are identified as potential targets, including military installations and sites where hazards such as heat, gases, and toxins are manufactured or stored.

- Mesh networks can also be used for battlefield and shipboard monitoring.

Asset and inventory management

By tagging items with small end devices, they can be quickly located.

- Audits can be performed by a single person with a scanner instead of a room full of people manually counting.
- Theft and pilfering can be reduced by tracking when items are moved. In buildings where employees wear security tags, the network can also identify which employee moved each item, or activate security devices such as cameras when items are moved outside normal business hours.
- Organizations that transport and track goods, such as freight companies and the military, can use mesh networks to track individual items within shipments, and also help to protect the integrity of each shipment by identifying whether any items are added, removed or replaced.

Conclusion

Mesh networks are good at looking after themselves, with self configuration, self healing, self routing and self management capabilities.

Their low cost, scalability, and flexibility also make mesh networks good at looking after a wide range of applications, from saving you money through lower heating and lighting bills, to keeping track of the shipment details for your latest mail order indulgence, right through to protecting you against environmental dangers caused by chemical leaks, or saving your life by notifying a doctor immediately when a medical emergency occurs.

For something so powerful, wireless mesh networks can be remarkably affordable and accessible. They provide an ideal solution in harsh, dangerous, and difficult environments where devices are widely distributed. And are equally at home making sure your house is a comfortable temperature and you don't miss your favorite TV show.

As more and more devices become wireless and portable, the list of future applications for mesh networks continues to grow, helping to turn things that you used to only read about in science fiction into realities.

About Daintree Networks

Based in Mountain View, California, Daintree Networks is a clean technology company that provides wireless control solutions for commercial buildings. Daintree has a strong background in wireless sensor and control mesh networking, with extensive knowledge and experience gained through its industry-standard design verification and operational support tool, the Sensor Network Analyzer (SNA). In addition to wireless embedded expertise, Daintree has put together a team of seasoned professionals from the lighting, telecommunications and networking worlds. Daintree's expertise and knowledge is now being focused on the development of cost-effective building automation systems. These provide benefits including reduced energy consumption, costs and carbon footprint, compliance with new "green" building regulations, and cost savings available through government rebates and the ability to take advantage of demand response programs.

Daintree's Wireless Lighting Control Solution (WLCS) allows lighting manufacturers to speed their time to market, and enables them to deliver powerful, comprehensive, flexible, and reliable wireless lighting control systems for commercial buildings. For more information, visit www.daintree.net or email sales@daintree.net

Daintree Networks Inc
1503 Grant Road, Suite 202
Mountain View, CA 94040 U.S.A

(w) www.daintree.net
(e) sales@daintree.net
(p) +1 (650) 965-3454