ZIGBEE – A WIRELESS MESH

Abstract:

Wireless is hot but is it more then just a buzz? About 2 years ago I would have said that it is more a buzz then practical. The progress made with wireless technology has been very big. Today it's not a buzz; it's something to really take into consideration!

For the last few years, we've witnessed a great expansion of remote control devices in our day-to-day life. Five years ago, infrared (IR) remotes for the television were the only such devices in our homes. Now I quickly run out of fingers as I count the devices and appliances I can control remotely in my house. This number will only increase as more devices are controlled or monitored from a distance. To interact with all these remotely controlled devices, we'll need to put them under a single standardized control interface that can interconnect into a network, specifically a HAN or home-area network.

One of the most promising HAN protocols is ZigBee, a software layer based on the IEEE 802.15.4 standard. ZigBee is a wireless network standard that meets the unique needs of sensors and control devices. A ZigBee node is a simple thing. At its heart is a multichannel two-way radio and micro controller all on a single piece of silicon, tucked inside a plastic package about the size of your pinkie fingernail.

ZigBee includes the following key features:

- Reliability and self-healing
- Support for a large number of nodes
- Fast, easy deployment
- Very long battery life
- Security
- Low cost

ZigBee is based upon stack architecture that resembles standard OSI seven-layer model but defines only those layers relevant to achieving functionality in the intended scope.

Key Words: *Infrared remote, television, home area network.*

Conclusion: Multi-hop mesh technology like that supported by the ZigBee standard, however, is inherently reliable, redundant, and can be extended to include thousands of devices. Real-world examples cited in this paper demonstrate that ZigBee mesh networks can be installed in hours instead of days or weeks and that these networks are highly dependable.

Furthermore, flexible, self-configuring, self-healing ZigBee networks are inherently less expensive to install and maintain. Hence, a significant barrier to low-cost connectivity has been removed.

INTRODUCTION:

Reliable data delivery is critical to ZigBee applications. The underlying IEEE 802.15.4 standard provides strong reliability through several mechanisms at multiple layers.
IEEE 802.15.4 is a standard defined by the IEEE (Institute of Electrical and Electronics Engineers, Inc.) for low-rate, wireless personal area networks (WPANs). This standard defines the "physical layer" and the "medium access layer." The specification for the physical layer, or PHY, defines a low-power spread spectrum radio operating at 2.4 GHz with a basic bit rate of 250 kilobits per second. There are also PHY specifications for 915 MHz and 868 MHz that operate at lower data rates.
In industry ZigBee is being used for next generation automated manufacturing, with small transmitters in every device on the floor, allowing for communication between devices to a central computer. This new level of communication permits finely-tuned remote monitoring and manipulation. In the consumer market ZigBee is being explored for everything from linking low-power household devices such as smoke alarms to a central housing control unit, to centralized light controls.

ZIGBEE:

ZigBee Module

The term "**ZigBee**" originates from honeybees' method of communicating newfound food sources. This silent-but-powerful communication system is known as the "ZigBee Principle." By dancing in the erratic zigging patterns the bee is able to share critical information, such as the location, distance, and direction of a newly discovered food source to its fellow hive members. This is evocative of the invisible webs of connections existing in a fully wireless environment.

WHAT IS ZIGBEE?

ZigBee is a home-area network designed specifically to replace the proliferation of individual remote controls. ZigBee's possibilities go far beyond light switches. For several years there have been sensor technologies that could transform the home. What we haven't had, until now, is a cost-effective way to use them. ZigBee was created to satisfy the market's need for a cost-effective, standards-based wireless network that supports low data rates, low power consumption, security, and reliability, which is suitable for operation in harsh radio environments and in isolated locations. ZigBee takes full advantage of a powerful physical radio specified by IEEE 802.15.4, adding logical network, security and application software to the specification. The standard itself is regulated by a group known as the ZigBee Alliance, with over 150 members worldwide.
ZigBee is the result of collaborative efforts by a global consortium of companies known as the ZigBee Alliance .To address this need, the ZigBee Alliance, an industry working group is developing standardized application software on top of the IEEE 802.15.4 wireless standard. The alliance is working closely with the IEEE to ensure an integrated, complete, and interoperable network for the market.The ZigBee Alliance will also serve as the official test and certification group for ZigBee devices.

The wireless mesh networks as specified in the new ZigBee networking standard are multi-hop systems in which devices assist each other in transmitting packets through the network, especially in adverse conditions. ZigBee nodes can be dropped in place ad hoc with minimal preparation and provide a reliable, flexible system that can be extended to thousands of devices.

OBJECTIVES:

ZigBee mesh networks meet all the objectives of industrial sensing and control applications:

- The network does not require sophisticated planning and site mapping to achieve reliable communications. There is no need for specialized, expensive labor to complete the installation.

- The network is self-configuring, and does not require the assistance of a network specialist just to send a packet from one end to the other.
- All devices are able to transmit from where they are originally, and do not have to be moved. A weak signal or "dead zone" can be fixed simply by dropping a repeater node in place.
- Compared to the cost of specialized knowledge that's required to install traditional wireless systems, or the cost of point-to-point copper wiring and conduit, ZigBee is must less expensive.
- The network error rate is very low (under 0.1% in the example cited above) and can be further reduced if occasional re-transmits are allowed.

FEATURES:

ZigBee is poised to become the global control/sensor network standard. It has been designed to provide the following features:

- ***Low power consumption, simply implemented***

Users expect batteries to last many months to years! Consider that a typical single family house has about 6 smoke/CO detectors. If the batteries for each one only lasted six months, the home owner would be replacing batteries every month!

- ***Robust***

IEEE802.15.4 provides a robust foundation for ZigBee, ensuring a reliable solution in noisy environments. Features such as energy detection, clear channel assessment and channel selection help the device pick the best possible channel, avoiding other wireless networks such as Wi-Fi®. Message acknowledgement helps to ensure that the data was delivered to its destination. Finally, multiple levels of security ensure that the network and data remain intact and secure.

- ***High density of nodes per network***

ZigBee's use of the IEEE 802.15.4 PHY and MAC allows networks to handle any number of devices. This attribute is critical for massive sensor arrays and control networks.

- ***Simple protocol, global implementation***

ZigBee's protocol code stack is estimated to be about 1/4th of Bluetooth's or 802.11's. Simplicity is essential to cost, interoperability, and maintenance. The IEEE 802.15.4 PHY adopted by ZigBee has been designed for the 868 MHz band in Europe, the 915 MHz band in N America, Australia, etc; and the 2.4 GHz band is now recognized to be a global band accepted in almost all countries.

- ***Low cost***

Low cost to the users means low device cost, low installation cost and low maintenance. ZigBee devices allow batteries to last up to years using primary cells (low cost) without any

chargers (low cost and easy installation). ZigBee's simplicity allows for inherent configuration and redundancy of network devices provides low maintenance.

- ***Mesh Networking***

The ability to cover large areas with routers is one of the key features of ZigBee that helps differentiate itself from other technologies. Mesh networking can extend the range of the network through routing, while self healing increases the reliability of the network by re-routing a message in case of a node failure

- ***Interoperability***

The ZigBee Alliance helps ensure interoperability between vendors by creating testing and certification programs for ZigBee devices. Users can be assured the devices that go through certification testing and use the ZigBee logo will work with other devices based on the same applications. This provides end customers with the customers with peace of mind while creating brand awareness of products with the ZigBee logo.

CHARACTERISTICS:

The General Characteristics of ZigBee are:

- Dual PHY (2.4GHz and 868/915 MHz)
- Data rates of 250 kbps (@2.4 GHz), 40 kbps (@ 915 MHz), and 20 kbps (@868 MHz)
- Optimized for low duty-cycle applications (<0.1%)
- CSMA-CA channel access
  - Yields high throughout and low latency for low duty cycle devices like sensors and controls
- Low power (battery life multi-month to years)
- Multiple topologies: star, peer-to-peer, mesh
- Addressing space of up to:
  - 18,450,000,000,000,000,000 devices (64 bit IEEE address)
  - 65,535 networks
- Optional guaranteed time slot for applications requiring low latency
- Fully hand-shaked protocol for transfer reliability
- Range: 50m typical (5-500m based on environment)

ZIGBEE NETWORK TOPOLOGIES:

There are three different network topologies that are supported by ZigBee, namely the star, mesh and cluster tree or hybrid networks. Each has its own advantages and can be used to advantage in different situations.

The star network is commonly used, having the advantage of simplicity. As the name suggests it is formed in a star configuration with outlying nodes communicating with a central node.

Mesh or peer-to-peer networks enable high degrees of reliability. They consist of a variety of nodes placed as needed, and nodes within range being able to communicate with each other to form a mesh. Messages may be routed across the network using the different stations as relays. There is usually a choice of routes that can be used and this makes the network very robust. If interference is present on one section of a network, then another can be used instead.

Finally there is what is known as a cluster tree network. This is essentially a combination of star and mesh topologies.

GATEWAY :

There is another important type of ZigBee Node: Gateway:Its responsibilities are to interface a ZigBee network into an external system, and to provide inter-network communications. Gateways clear the way for ZigBee integration with existing and co-existing systems, for arrangement a global network that unites a number of underlying ZigBee networks as well as other solutions and information systems. ZigBee Gateway is intended to provide an interface between ZigBee and IP devices through an abstracted interface on the IP side. The IP device is isolated from the ZigBee protocol by that interface. The ZigBee Gateway translates both addresses and commands between ZigBee and IP.

ZIGBEE DEVICES:

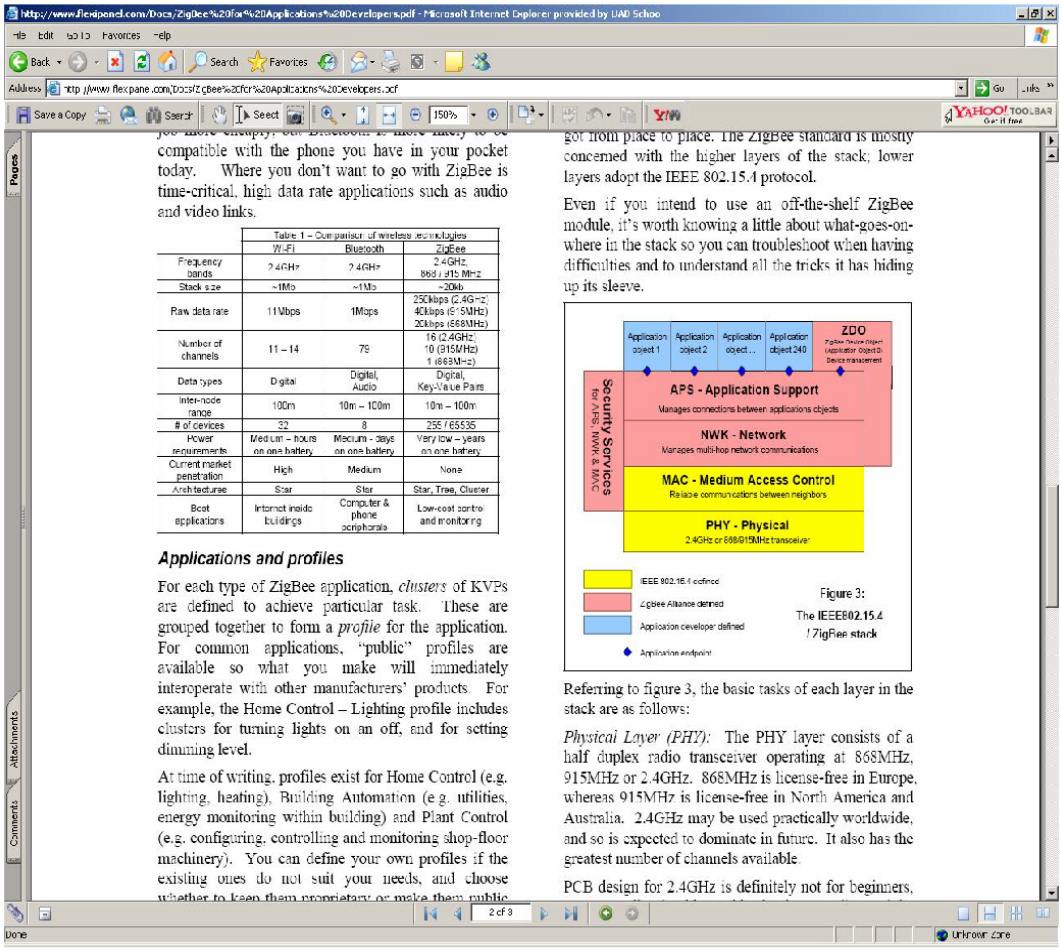
ZigBee networks use three device types:

- ***The network coordinator*** maintains overall network knowledge. It's the most sophisticated of the three types and requires the most memory and computing power.
- ***The full function device (FFD)*** supports all 802.15.4 functions and features specified by the standard. It can function as a network coordinator. Additional memory and computing power make it ideal for network router functions or it could be used in network-edge devices (where the network touches the real world).
- ***The reduced function device (RFD)*** carries limited (as specified by the standard) functionality to lower cost and complexity. It's generally found in network-edge devices.

ZIGBEE STACK:

The ZigBee stack is small in comparison to other wireless standards. For network-edge devices with limited capabilities, the stack requires about 4Kb of the memory. Full implementation of the protocol stack takes less than 32Kb of memory. The network coordinator may require extra RAM for a node devices database and for transaction and pairing tables. The 802.15.4 standard defines 26 primitives for the PHY and MAC layers; probably another dozen will be added after finalizing the NWK layer specification.

Those numbers are still modest compared to 131 primitives defined for Bluetooth. Such a compact footprint enables you to run ZigBee on a simple 8-bit microcontroller such as an HC08 or 8051based processor core.



compatible with the phone you have in your pocket today. Where you don't want to go with ZigBee is time-critical, high data rate applications such as audio and video links.

	Table 1 – Comparison of wireless technologies		
	Wi-Fi	Bluetooth	ZigBee
Frequency bands	2.4GHz	2.4GHz	2.4GHz, 868 / 915 MHz
Stack size	~1Mb	~1Mb	~20kb
Raw data rate	11Mbps	1Mbps	250kbps (2.4G~z), 40kbps (915MHz) 20kbps (868MHz)
Number of channels	11 – 14	79	16 (2.4GHz), 10 (915MHz) 1 (868MHz)
Data types	Digital	Digital, Audio	Digital, Key-Value Pairs
Inter-node range	100m	10m – 100m	10m – 100m
# of devices	32	8	255 / 65535
Power requirements	Medium – hours on one battery	Medium - days on one battery	Very low – years on one battery
Current market penetration	High	Medium	None
Architecture	Star	Star	Star, Tree, Cluster
Best applications	Internet inside buildings	Computer & phone peripherals	Low-cost control and monitoring

Applications and profiles

For each type of ZigBee application, *clusters* of KVPs are defined to achieve particular task. These are grouped together to form a *profile* for the application. For common applications, "public" profiles are available so what you make will immediately interoperate with other manufacturers' products. For example, the Home Control – Lighting profile includes clusters for turning lights on an off, and for setting dimming level.

At time of writing, profiles exist for Home Control (e.g. lighting, heating), Building Automation (e.g. utilities, energy monitoring within building) and Plant Control (e.g. configuring, controlling and monitoring shop-floor machinery). You can define your own profiles if the existing ones do not suit your needs, and choose whether to keep them proprietary or make them public

got from place to place. The ZigBee standard is mostly concerned with the higher layers of the stack; lower layers adopt the IEEE 802.15.4 protocol.

Even if you intend to use an off-the-shelf ZigBee module, it's worth knowing a little about what-goes-on-where in the stack so you can troubleshoot when having difficulties and to understand all the tricks it has hiding up its sleeve.

Figure 3: The IEEE802.15.4 / ZigBee stack

Referring to figure 3, the basic tasks of each layer in the stack are as follows:

Physical Layer (PHY): The PHY layer consists of a half duplex radio transceiver operating at 868MHz, 915MHz or 2.4GHz. 868MHz is license-free in Europe, whereas 915MHz is license-free in North America and Australia. 2.4GHz may be used practically worldwide, and so is expected to dominate in future. It also has the greatest number of channels available.

PCB design for 2.4GHz is definitely not for beginners,

ZigBee Stack Architecture

As can be seen in the figure, IEEE 802.15.4 develops the Medium Access Control (MAC) Layer and Physical (PHY) Layer, which address such things as the frequency and data rate specifications. The Physical Layer also allows for two types of devices: full function devices (FFD's) and reduced function devices (RFD's). ZigBee, meanwhile, develops the Network Layer and Application Layer, which includes the Applications Support Sublayer, the ZigBee Device Object, and the Security Services. The Network Layer and Application Layer are more specific than the IEEE layers and involve such things as how a ZigBee network is to be set up, how the devices in the network relate to one another, and so on.

COMPARISON:

The following are the comparisons of ZigBee with:

- ***Bluetooth:***

While Bluetooth focuses on connectivity between large packet user devices, such as laptops, phones, and major peripherals, ZigBee is designed to provide highly efficient connectivity between small packet devices. As a result of its simplified operations, which are one to two full orders of magnitude less complex than a comparable Bluetooth device, pricing for ZigBee devices is extremely competitive, with full nodes available for a fraction of the cost of a Bluetooth node. ZigBee devices are actively limited to a through-rate of 250Kbps, compared to Bluetooth's much larger pipeline of 1Mbps, operating on the 2.4 GHz ISM band, which is available throughout most of the world.

- ***Wi-Fi:***

Like IEEE 802.11, known more commonly as Wi-Fi, ZigBee is a local area networking technology that blankets a home with wireless coverage. But in other ways, the two standards couldn't be more different. Wi-Fi uses a ton of power to provide a torrent of data, while ZigBee uses almost none to provide a trickle. Wi-Fi uses a single central router to radiate its coverage, whereas ZigBee builds up coverage out of small nodes that join together into a network.
ZigBee has a data rate of 250kbps, pitiful compared with Wi-Fi, which is hitting throughput of 20Mbps or more. But because ZigBee transmits slowly, it doesn't need much power, so batteries will last up to 10 years.

APPLICATIONS:

ZigBee is well suited for a wide range of building automation, industrial, medical and residential control and monitoring applications. Examples include the following:

- Lighting controls
- Automatic Meter Reading
- Wireless smoke and CO detectors
- HVAC control
- Heating control
- Home control, including units such as intrusion sensors, motion detectors, glass break detectors, standing water sensors, loud sound detectors, etc
- Environmental controls
- Blind, drapery and shade controls
- Medical sensing and monitoring
- Universal Remote Control to a Set-Top Box which includes Home Control
- Industrial and building automation
- Asset management