Future Role of ZigBee in Communication Systems

Raman Ratnakar Singh, Savita Shiwani

***Abstract*— ZigBee is an IEEE 802.15.4 standard for data communications with business and consumer devices. It is designed around low-power consumption allowing batteries to essentially last forever.**
The ZigBee standard provides network, security, and application support services operating on top of the IEEE 802.15.4 Medium Access Control (MAC) and Physical Layer (PHY) wireless standard. It employs a suite of technologies to enable scalable, self-organizing, self-healing networks that can manage various data traffic patterns.
ZigBee is a low-cost, low-power, wireless mesh networking standard.

The low cost allows the technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range. ZigBee has been developed to meet the growing demand for capable wireless networking between numerous low power devices. 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.

***Index Terms*— Medium Access Control (MAC), Physical Layer (PHY), Wireless Personal Area Networking (WPAN), Open Systems Interconnection (OSI)**

I. INTRODUCTION

ZigBee is an established set of specifications for wireless personal area networking (WPAN), i.e. digital radio connections between computers and related devices. WPAN Low Rate or ZigBee provides specifications for devices that have low data rates, consume very low power and are thus characterized by long battery life. ZigBee makes possible completely networked homes where all devices are able to communicate and be controlled by a single unit. The ZigBee Alliance, the standards body which defines ZigBee, also publishes application profiles that allow multiple OEM vendors to create interoperable products. The current list of application profiles either published or in the works are:

- Home Automation
- ZigBee Smart Energy
- Telecommunication Applications
- Personal Home

The relationship between IEEE 802.15.4 and ZigBee is similar to that between IEEE 802.11 and the Wi-Fi Alliance.

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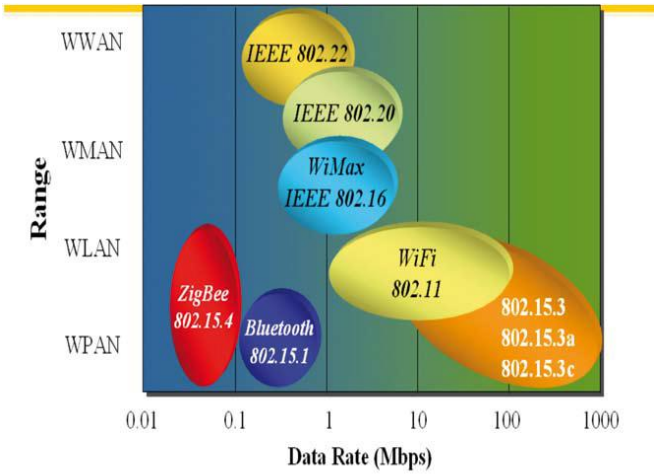
For non-commercial purposes, the ZigBee specification is available free to the general public. An entry level membership in the ZigBee Alliance, called Adopter, costs US$ 3500 annually and provides access to the as-yet unpublished specifications and permission to create products for market using the specifications. ZigBee is one of the global standards of communication protocol formulated by the relevant task force under the IEEE 802.15 working group. The fourth in the series, WPAN Low Rate/ZigBee is the newest and provides specifications for devices that have low data rates, consume very low power and are thus characterized by long battery life. Other standards like Bluetooth and IrDA address high data rate applications such as voice, video and LAN communications.

II. WHAT IS ZIGBEE?

ZigBee is a set of specifications created specifically for control and sensor networks. Built on IEEE 802.15.4, the standard for low data rate wireless personal area networks (WPANs), it was developed by the ZigBee Alliance.
Formed in 2002, the Zigbee Alliance brings together public and private industry leaders who sought to address the need for a single standard that would ensure the interoperability of proprietary wireless sensors and control systems both with each other and newer technologies. Such systems require low latency, low data rates, low cost, and low energy consumption.
IEEE standard 802.15.4, which defines the physical layer (PHY) and media access control (MAC) for low-rate WPANs, restricts the data rate to 250 kbps in the global 2.4-GHz Industrial, Scientific, Medical (ISM) band, while also specifying low power consumption and cost. Taking the low-level PHY and MAC layers as their base, the Zigbee Alliance developed Zigbee – the network protocol, security, and application layers for low-rate WPANs.
Since the ZigBee specification was released in 2006, it has developed to the point where is it now poised to become the global control/sensor network standard for a wide and varied range of residential, industrial, and commercial applications. It enables wireless two-way communications between commands and controls (e.g. boiler and thermostat), travels as far as 75-100 meters, and controls sensors that perform many different tasks.
Residential and commercial applications include lighting controls, smoke and CO2 detectors, HVAC controls, home security, automatic utility meter readings, and communication between a remote control and a digital set-top box. And, with mobile telephone operators integrating ZigBee into phones and PDAs, consumers can use their cell phones as their single remote control device. In industry, examples are monitoring

medical equipment, building and industrial automation, and environmental controls.
The secret of ZigBee's success is that it is fit to purpose. At 250 kbps, ZigBee's data rate is hundreds of times lower than WiFi's. But it does not need to be higher. An intrusion sensor, for example, does not need to transmit and receive much data. In fact, low data rates mean low power requirements. ZigBee's very low energy consumption (door opening sensors, for instance, can run for five years on an ordinary AAA battery) is an economic and ecological advantage. It is related to the way ZigBee networks work.



Voice over wireless sensor networks has seen a tremendous growth in both business and consumer sectors. Wireless sensor networks are of low cost and consumes less power, thus in this realm we will study how to transmit moderate quality of voice signal using 8-bit microcontroller through Zigbee.
The first and foremost question that comes into mind is that why Zigbee should be considered for audio applications, especially when other alternatives such as Bluetooth, WI-Fi already cater for such needs?
There are several arguments that go in favor of Zigbee, at least for a certain category of audio applications:

- Zigbee has a defined data transfer rate of 250 kbps and the data rate required for the transmission of audio signal, mainly varies from tens of kbps to hundreds of kbps, making Zigbee an alternative for low end and mid end applications.
- Zigbee is well suited for transmission of regular, irregular data or a single signal transmission from input device or sensors.
- Zigbee features power saving techniques so that deep sleeps can be handled efficiently with rapid wake up and rapid fall into sleep features. Thus, Zigbee wireless sensors can last for years without change in battery.
- The software size of Zigbee stack is only 1/10 (one tenth) of a Bluetooth stack.

Zigbee technology consists of a suite of specifications designed particularly for wireless network sensor and controllers, based on IEEE 802 standard for personal area network. Zigbee has a defined data rate of 250 kbps suitable for transmission of regular or irregular data from the input device. The name "Zigbee" refers to waggle (to move impatiently) dance of honey bees after their return to their beehives. Zigbee is a cheap, more power efficient, wireless sensor network standard. The low cost feature of Zigbee allows it to be widely employed in wireless control and monitoring applications while the low power consumption feature provides longer life to the equipments.

A. *ZIGBEE CHARACTERISTICS*

The focus of network applications under the IEEE 802.15.4 / ZigBee standard include the features of low power consumption, needed for only two major modes (Tx/Rx or Sleep), high density of nodes per network, low costs and simple implementation.
These features are enabled by the following characteristics,

• *2.4GHz and 868/915 MHz dual PHY modes*. This represents three license-free bands: 2.4-2.4835 GHz, 868-870 MHz and 902-928 MHz the number of channels allotted to each frequency band is fixed at sixteen (numbered 11-26), one (numbered 0) and ten (numbered 1-10) respectively. The higher frequency band is applicable worldwide, and the lower band in the areas of North America, Europe, Australia and New Zealand.

• Low power consumption, with battery life ranging from months to years. Considering the number of devices with remotes in use at present, it is easy to see that more numbers of batteries need to be provisioned every so often, entailing regular (as well as timely), recurring expenditure. In the ZigBee standard, longer battery life is achievable by either of two means: continuous network connection and slow but sure battery drain, or intermittent connection and even slower battery drain.

• Maximum data rates allowed for each of these frequency bands are fixed as 250 kbps @2.4 GHz, 40 kbps @ 915 MHz, and 20 kbps @868 MHz.
• High throughput and low latency for low duty cycle applications (<0.1%)
• Channel access using Carrier Sense Multiple
Access with Collision Avoidance (CSMA - CA)
• Addressing space of up to 64 bit IEEE address devices, 65,535 networks
• 50m typical range
• Fully reliable "hand-shaked" data transfer protocol.
• Different topologies as illustrated below: star, peer-to-peer, mesh

III. TRAFFIC TYPES

ZigBee/IEEE 802.15.4 addresses three typical traffic types. IEEE 802.15.4 MAC can accommodate all the types.

1. Data is *periodic*. The application dictates the rate, and the sensor activates, checks for data and deactivates.

2. Data is *intermittent*. The application, or other stimulus, determines the rate, as in the case of say smoke detectors. The

device needs to connect to the network only when communication is necessitated. This type enables optimum saving on energy.

3. Data is *repetitive*, and the rate is fixed a priori. Depending on allotted time slots, called GTS (guaranteed time slot), devices operate for fixed durations.

ZigBee employs either of two modes, beacon or non-beacon to enable the to-and-fro data traffic. Beacon mode is used when the coordinator runs on batteries and thus offers maximum power savings, whereas the non-beacon mode finds favour when the coordinator is mains-powered. In the beacon mode, a device watches out for the coordinator's beacon that gets transmitted at periodically, locks on and looks for messages addressed to it. If message transmission is complete, the coordinator dictates a schedule for the next beacon so that the device ‘goes to sleep'; in fact, the coordinator itself switches to sleep mode.
While using the beacon mode, all the devices in a mesh network know when to communicate with each other. In this mode, necessarily, the timing circuits have to be quite accurate, or wake up sooner to be sure not to miss the beacon. This in turn means an increase in power consumption by the coordinator's receiver, entailing an optimal increase in costs.

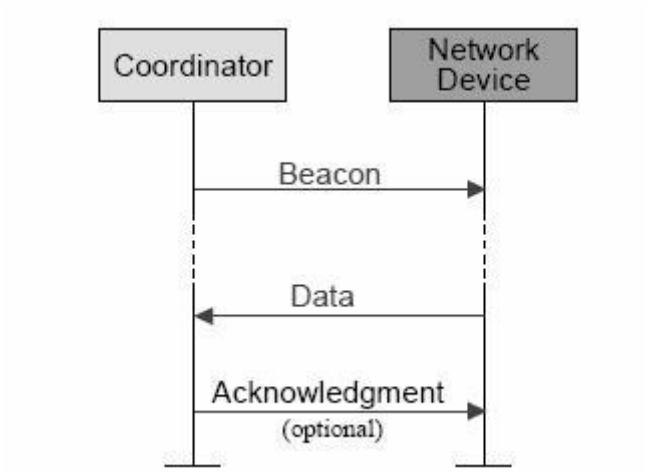


Figure : Beacon Network Communication
*[*Source:www.zigbee.org/en/resources]

The non-beacon mode will be included in a system where devices are ‘asleep' nearly always, as in smoke detectors and burglar alarms. The devices wake up and confirm their continued presence in the network at random intervals.
On detection of activity, the sensors ‘spring to attention', as it were, and transmit to the everwaiting coordinator's receiver (since it is mainspowered).
However, there is the remotest of chances that a sensor finds the channel busy, in which case the receiver unfortunately would ‘miss a call'.

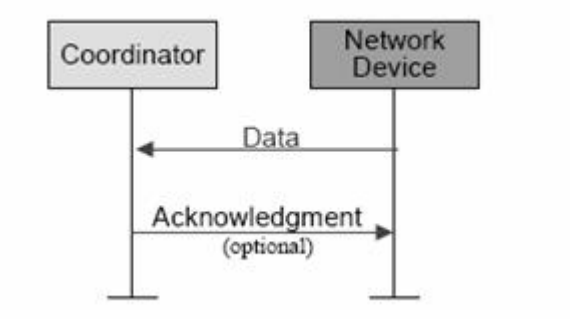


Figure : Non-Beacon Network Communication
*[*Source:www.zigbee.org/en/resources]

IV. ZIGBEE AND OTHER WIRELESS TECHNOLOGIES

ZigBee and other wireless technologies

Market Name / Standard	ZigBee™ 802.15.4	GSM/GPRS CDMA/1xRTT	Wi-Fi™ 802.11b	Bluetooth™ 802.15.1
Application Focus	Monitoring & Control	White Area Voice & Data	Web, Email, Video	Cable Replacement
System Resources	4KB - 32KB	16MB	1MB	16KB
Battery Life (days)	100 - 1,000	1 - 7	.5 - 5	1 - 7
Network Size	Unlimited	·	32	7
Bandwidth (KB/s)	20 - 250	124 - 68	11,000	720
Transmission Range (meters)	1 - 100	1,000	1 - 100	1 - 10
Success Metrics	Reliability, Power, Cost	Reach, Quality	Speed, Flexibility	Cost, Convenience

V. ARCHITECTURE

ZigBee is a home-area network designed specifically to replace the proliferation of individual remote controls. 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. To address this need, the ZigBee
Alliance, an industry working group
(www.zigbee.org), 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. For example, the working group will provide interoperability certification testing of 802.15.4 systems that include the ZigBee software layer.
The ZigBee Alliance will also serve as the official test and certification group for ZigBee devices. ZigBee is the only standards-based technology that addresses the needs of most remote monitoring and control and sensory network applications.

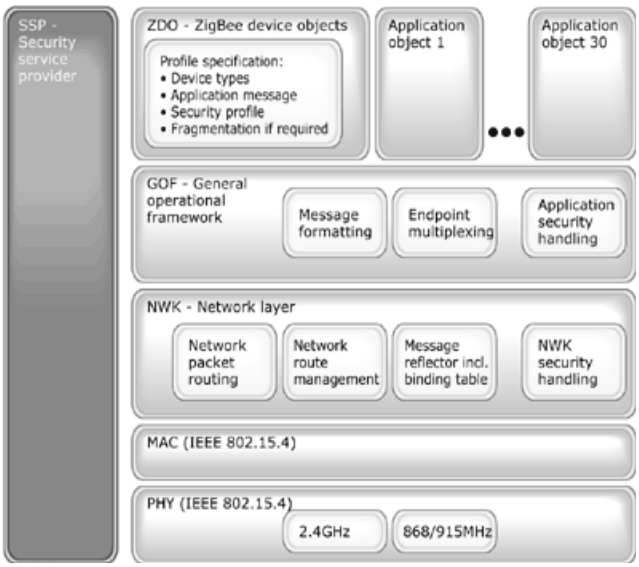


Figure : ZigBee stack architecture

VI. FRAME STRUCTURE

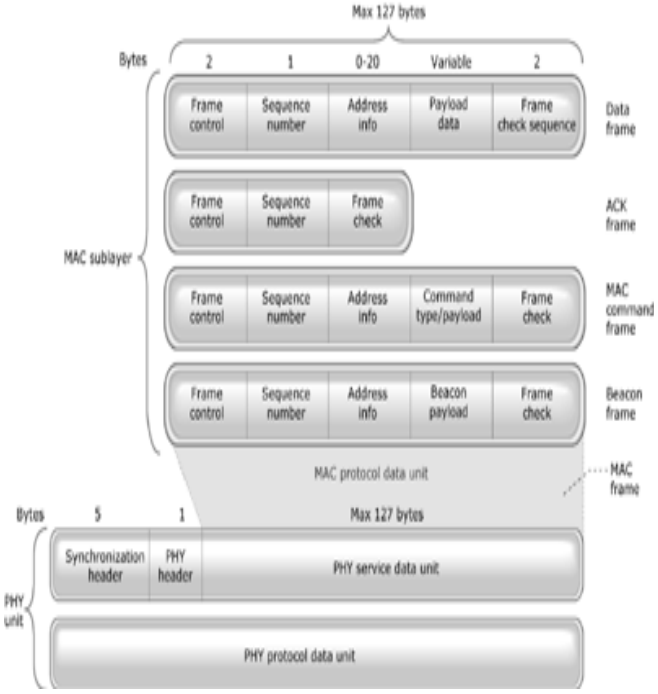


Figure: The four basic frame types defined in 802.15.4: Data, ACK, MAC command, and beacon

The *data frame* provides a payload of up to 104 bytes. The frame is numbered to ensure that all packets are tracked. A frame-check sequence ensures that packets are received without error.
This frame structure improves reliability in difficult conditions.
Another important structure for 802.15.4 is the *acknowledgment (ACK) frame*. It provides feedback from the receiver to the sender confirming that the packet was received without error. The device takes advantage of specified "quiet time" between frames to send a short packet immediately after the data packet transmission.
A *MAC command frame* provides the mechanism for remote control and configuration of client nodes. A centralized network manager uses MAC to configure individual clients' command frames no matter how large the network.
Finally, the *beacon frame* wakes up client devices, which listen for their address and go back to sleep if they don't receive it. Beacons are important for mesh and cluster-tree networks to keep all the nodes synchronized without requiring those nodes to consume precious battery energy by listening for long periods of time.

VII. DEVICE TYPES

These devices have 64-bit IEEE addresses, with option to enable shorter addresses to reduce packet size, and work in either of two addressing modes – star and peer-to-peer.

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.

VIII. SECURITY

Security and data integrity are key benefits of the ZigBee technology. ZigBee leverages the security model of the IEEE 802.15.4 MAC sublayer which specifies four security services:

• access control—the device maintains a list of trusted devices within the network.

• data encryption, which uses symmetric key 128-bit advanced encryption standard.

• frame integrity to protect data from being modified by parties without cryptographic keys.

• sequential freshness to reject data frames that have been replayed—the network controller compares the freshness value with the last known value from the device and rejects it if the freshness value has not been updated to a new value.

IX. CONLUSION

It is likely that ZigBee will increasingly play an important role in the future of computer and communication technology. In terms of protocol stack size, ZigBee's 32 KB is about one-third of the stack size necessary in other wireless technologies (for limited capability end devices, the stack size is as low as 4 KB). The IEEE 802.15.4–based ZigBee is designed for remote controls and sensors, which are very many in number, but need only small data packets and, mainly, extremely low power consumption for (long) life. Therefore they are naturally different in their approach to their respective application arenas. The ZigBee Alliance targets applications "across consumer, commercial, industrial and government markets worldwide". Unwired applications are highly sought after in many networks that are characterized by numerous nodes consuming minimum power and enjoying long battery lives. ZigBee technology is designed to best suit these applications, for the reason that it enables reduced costs of development and very fast market adoption.

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