A Review on Wireless Home Automation Systems based on Zigbee Technology

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Abstract- Development in wireless home automation has resulted in enriching the consumer experience in very simple manner. Home automation is one of the major application areas of ZigBee wireless networking. This paper reviews ZigBee Technology and its application in Wireless Home Automation Systems and compares it with other major existing technologies in implementing WHAS. The paper also lists some future opportunities and the challenges that ZigBee holds in this field.

Keywords- *Wireless Home Automation System, ZigBee, IEEE 802.15.4, voice control, energy management, security.*

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INTRODUCTION

Home automation describes everything- lights, appliances, electrical outlets, heating, and cooling systems, which are directly controlled through a remotely located control network. And thus, home automation refers to the automatic and electronic control of household features, activity, and appliances. According to Smart Home Energy [15], a smart house is a house that incorporates sophisticated monitoring and control over the building unctions in order to provide inhabitants.

Multifarious access to the electronic and electrical devices in their homes. Some of the applications include light control, home security, smart irrigation system, energy regulation, and Heating Ventilation and Air Conditioning (HVAC) control. In recent years, there has been a lot of development in this area. Some of the already established wireless standards [16]suchas WLAN (Wireless Local Area Network), WWAN (Wireless Wide Area Network), CDMA2000 render infeasibility due to their high power consumption and thus cannot be used in low power devices. Many new technologies have emerged which promise better security, better reliability, and much-refined user experience. Some of them include Bluetooth [17], Wi-Fi [18], Insteon [19], Z-wave [20], Wavenis [21], and ZIGBEE [22]. In this paper, we have focused on WHAS based on ZIGBEE. In the early part of this paper, we have discussed what actually ZigBee is.Section two describes a comprehensive analysis of the application of ZigBee in WHAS and the major bottlenecks that ZigBee faces and some of the methods are proposed in order to overcome these challenges. Section three of this paper compares ZigBee with various other existing technologies in WHAS. Finally, this paper is concluded with section 4.

IEEE 802.15.4 AND THE ZIGBEE

This section provides an introduction to the ZigBee standard for short-range wireless networking.ZigBee is the open, global wireless standard to provide the foundation for the Internet of Things by enabling simple and smart objects to work together, improving comfort and efficiency in everyday life.

ZigBee is a standard that defines a set of communication protocols for low data rate, low power, low-cost short-range wireless networking. ZigBee has a maximum defined rate of 250 kbps. ZigBee operates in the industrial, scientific and medical (ISM) radio bands: 2.4 GHz in most jurisdictions worldwide, 868 MHz in Europe and 915 MHz in USA and Australia. Since ZigBee-based devices are battery powered, most of these devices spend their considerable time in power saving mode also called as sleep mode.

The ZigBee standard is developed by ZigBee Alliance. ZigBee protocol layers are based on the Open System Interconnect (OSI) reference model. The ZigBee standard has adopted IEEE 802.15.4 [23] as its Physical Layer and Medium Access Control (Mac) layer protocols. The IEEE 802.15.4 defines the specifications for Physical and MAC layer for implementing Wireless Personal Area Network (WPAN) but it does not specify any protocols for higher networking layers. ZigBee is built on top of IEEE 802.15.4 and ZigBee standard defines protocols only for Network and Application layers.

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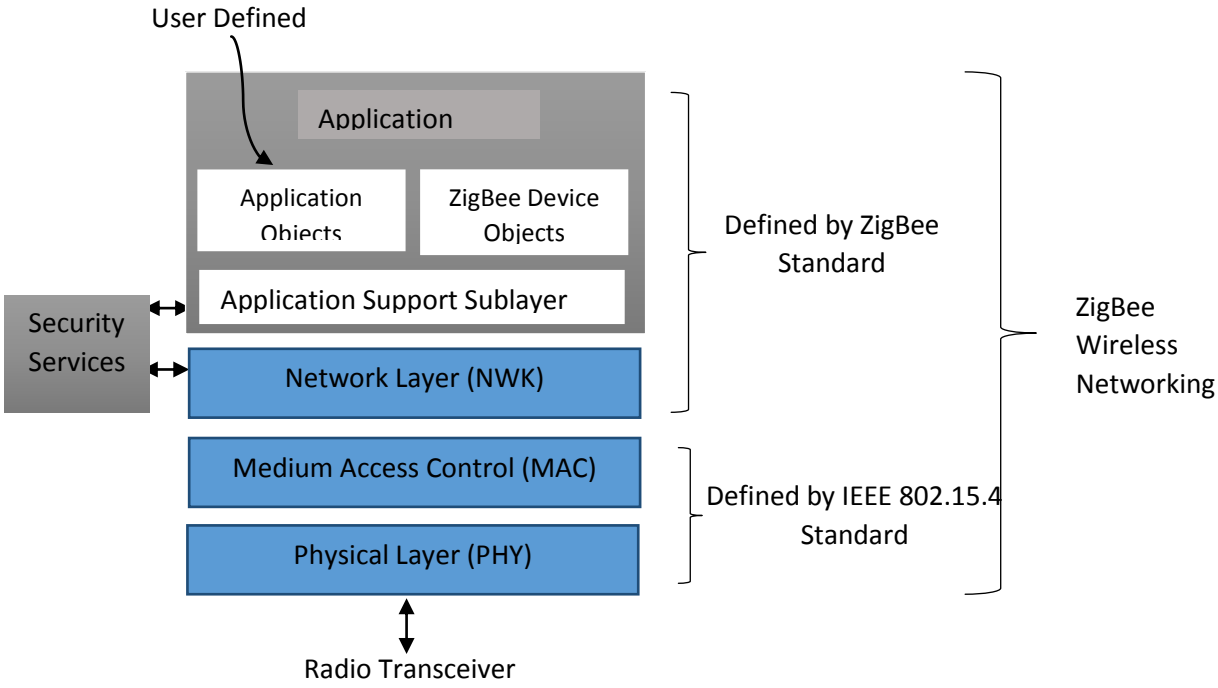


Fig 1: Relation between ZigBee and IEEE 802.15.4

DEVICE TYPES

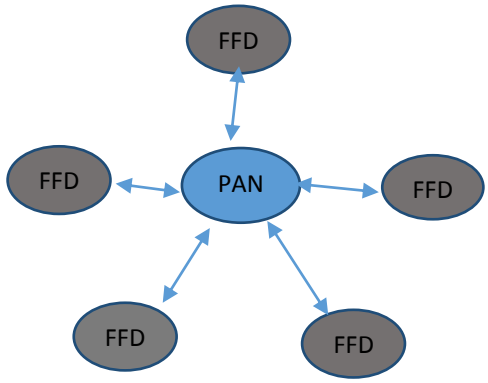
There are mainly two types of physical devices defined in IEEE 802.15.4: Full Function Device (FFD) and Reduced Function Device (RFD) [1]. FFD can accept any role in network and can communicate with any device in the network and thus FFDs perform routing functions. RFDs communicate only to FFDs and thus do not take part in routing functions. FFDs are further divided into following three logical devices: PAN (Personal Area Network) coordinator, coordinator, and an end device. The PAN coordinator is the principal controller of PAN and initiates the formation of the network tree.

Coordinator acts as a router and relays messages. The end device doesn't take part in routing and communicates only with a coordinator.

NETWORKING TOPOLOGIES

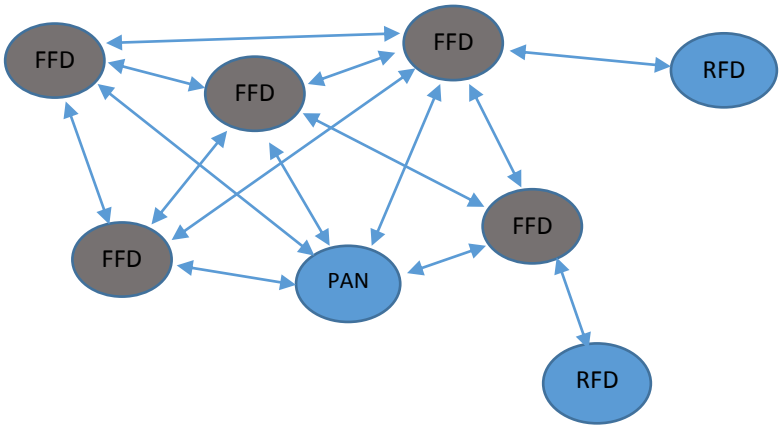
ZigBee networking layer manages the network formations [1]. Two networking topologies are allowed in IEEE 802.15.4: Star topology and peer to peer topology. In a star topology, every device in the network communicates only to one PAN Coordinator. In peer- to –peer topology, each device can communicate directly to its nearby device i.e. coordinators among themselves, between PAN coordinators and end devices withcoordinators.

Peer-to-peer is further classified intotwo kinds of networks: Mesh Network and Tree Network.



(a) PAN: PAN coordinator

FFD: Full Function device



(b) PAN: PAN coordinator FFD: Full Function device

Fig 2: ZigBee Topologies (a) Star topology (b) Mesh topology

Table 1: ZigBee Characteristics

PARAMETER	VALUE
FREQUENCY	868 MHz (Europe) 915 MHz (USA and Australia) 2.4 GHz (Rest of the world)
DATA RATE	Up to 250 kbps
RANGE	10-20 meters
ADDRESS	16 bit to 64 bit
MULTIPLE ACCESS TECHNIQUES	CSMA-CA (Carrier sense multiple access with collision avoidance)

WHERE ZIGBEE STANDS AND PROBLEMS FACED BY ZIGBEE

The need for the hour for Home Automation is to create the best way to connect and control all devices at home with following characteristics in mind:

- Energy Management
- Security at home and thus not allowing eavesdropping
- Simple and easy to understand user interface
- Open standard protocol ensuring interoperability among devices
- Supporting an assortment of devices at home and widened the realm of HA controls like climate control, security control, energy management etc.

Keeping these characteristics in mind, it can be safe to say that ZigBee projects itself as a strong contender in wireless home automation system technology. This section presents the survey work on WHAS based on ZigBee.

Electric power management has been proposed in [2]. The proposed system contains a control unit and the end device unit, both having ZigBee interface, GSM modem, Power measurement IC and ARM7. It proposes a system where Wireless Sensor Network will differentiate and control the devices in the network based on the power consumed by that device and thus allows only low power devices to be ON. ARM7 microcontroller sets the threshold power for end devices through the wireless communication based on ZigBee protocol. The control unit is further remotely programmable through GSM.

Intelligent Home Automation System (IHAS) has been proposed in [3] which uses PIC microcontroller, ZigBee technology, voice recognition technique and GSM to control home appliances. The proposed system also integrates a security warning system that would warn users about fire hazards. The command to the microcontroller is given by voice recognition module HM2007. The memory chip in the microcontroller compares the voice commands with the recorded voice. These commands are sent to control unit wirelessly using ZigBee protocol which further controls home appliances via relay unit. The system also uses a short message facility to warn users when a smoke is detected. This is achieved through GSM module connected to PIC controller.

For example, HA requires energy efficiency and ZigBee seems to be a good technology to implement in which devices have a duty cycle of 0.1% and spend most of their time in sleep mode. [4] Says that ZigBee suggests two algorithms based on two operating modes in order to achieve energy efficiency. One is TDMA algorithm while another one is CSMA based. TDMA is very effective but is limited to star network while CSMA tries to reduce power usage using low duty cycles. However, research suggests that cross-layer approach can be more efficient where NWK and/or APS layer information is used to drive wireless operation. This is a complicated approach but can be developed in ZigBee standard.

[4] Shows how ZigBee has ensured security in the network by using symmetric cryptography mechanism. ZigBee proposes to use two session keys. These keys are link key and network key. The link key is used for communication between two nodes while the network key is used for broadcasting messages. Also, there is an initial master key that generated session keys. Also, ZigBee proposes that it provides encryption at three different layers (MAC, NWK, and APS) and each layer adds its own security command to the packet received from the upper layer.[13] and [14] propose a ZigBee-based intelligent self-adjusting sensor ZiSAS.

Implementation of Home Automation system finds a problem in the form of architectural constraint i.e. fixed system architecture. Due to this existing sensor systems are not suitable in a dynamic home environment. This paper thus proposes a situation based self-adjusting scheme, called as ZiSAS. The ZiSAS system was designed and implemented using related hardware and middleware in order to make consumer devices more energy efficient and smart. The proposed system is able to create the adaptive home services according to location and the resident. The ZiSAS system continuously gathers environment information and analyzes the current situation to provide the residents with context-aware services.

ZIGBEE TAKES ON BLUETOOTH

[5] Proposes a ZigBee-based HAS using voice recognition. The proposed system uses ZigBee model CC2520 with AT89S52 which is low power, high-performance CMOS, 8-bit microcontroller. Software used areKeiluvision software and speech recognition software. HM2007 voice recognition unit is used. The proposed system also shows how ZigBee outperforms Bluetooth. For example, this paper proposes that even though Bluetooth has higher data rate but ZigBee provides better coverage area than Bluetooth. Moreover, it also proposes that ZigBee has better response time than Bluetooth as the coverage increases.

PROBLEMS FACED BY ZIGBEE AND THEIR PROPOSED SOLUTIONS:

One limitation of ZigBee is that it is plagued with Orphan problem. It refers to a situation where a child node is unable to obtain a 16-bit network address from a parent device in order to join a network. [6] Discusses this problem and proposes algorithms that effectively reduce the number of orphan devices. The paper shows that orphan problem is divided into two sub-problems- a.BDDTF (Bounded Degree and Device Tree Formation, b. EDMM (End Device Maximum Matching). The paper claims and shows that existence of orphan is an inherent concern and a non-trivial one where a device is not guaranteed to join the network even if there are empty address spaces remaining in the network. The paper proves that BDDTF is NP-Complete and proposes a Centralized two-stage network formation policy, also called as Span and Prune algorithm which can be thought to consist of a sequence of iterations of network formation. Another algorithm proposed for BDDTF is Distributed Depth-then-Breadth Search algorithm. For EDMM problem, the paper proposes a distributed matching algorithm. All these algorithms show a better solution to the problem as compared to ZigBee network formation scheme.

Another limitation of ZigBee is its limited transmission range of its node. There are three ways to improve the range of these nodes. Either increasing the Transmitter output power or improving the receiver sensitivity or using mesh networking (also called as node hopping). Power Amplifier (PA) can be added to increase the output power and hence the range. The limitation of this method is that external PA would result in much higher power consumption of node and unwanted out-of-band emissions. Another method to extend the range is by improving receiver sensitivity. This can be achieved by using Low Noise Amplifier (LNA) which improves Noise Figure (NF) of the receiver. [7] Successfully shows the use of ZigBee front-end module (FEM) which extend the wireless range between nodes.Two devices, SKY65336, and SKY65337, are used. These

devices are shown to increase the free space range from 133m (of typical ZigBee transmitter) to 923m (with SKY65336) and indoor range from 16m to 81m.

DIFFERENT TECHNOLOGIES FOR WIRELESS HOME AUTOMATION

Due to the rising interest in WHAS many new technologies have emerged over the past few years.This section compares different wireless protocols of competing technologies. The technologies listed are ZigBee, Z-Wave, Insteon, Bluetooth, Wi- Fi, UWB, Wavenis, and EnOcean [8].

PARAMETERS	ZIGBEE	BLUETOOTH	WI-FI	Z-WAVE	INSTEON	UBW	WAVENIS
FREQUENCY	868 MHz 915 MHz 2.4 GHz	2.4 GHz	2.4 GHz 5 GHz	868 MHz 908 MHz 2.4 GHz(for 400 series only)	904 MHz(RF) / 131.65 (Powerline)	3.1-10.6 GHz	433 MHz 868 MHz 915 MHz
DATA RATE	20 to 50 kb/s	1 Mb/s	54 Mb/s	9600 bit/s, 40 kb/s or 100 Kb/s	13,165 b/s(powerline) /38,400 b/s (RF)	110 Mb/s to 1.6 Gb/s	4.8 kbps to 100 kbps
MODULATION	BPSK/ O-QPSK	GFSK	QPSK/COFDM/QAM	GFSK/FSK	BPSK(Powerline) /FSK(RF)	BPSK QPSK	GFSK
RANGE	10-100 m	10 m	~30 m	30-100 m	45(LOS)	10 m	1 km(25Mw)/4 km(500Mw)
POWER CONSUMPTION	Low	Medium	High	Low Power	NA	High	Very Low
IEEE STANDARD	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.11	-	-	IEEE 802.15.3a	-
SECURITY	AES	AES with CounterMode CBC-MAC	AES/RC4	AES 128	AES 256/Linking control	AES	3DES, AES-128, RSA, EMV
SPREADING	DSSS	FHSS	DSSS	-	No	DS-UWB/MB-OFDM	FHSS

Table 2: Comparison of Different WHAS Protocols

Z-Wave is low powered home automation technology mainly intending to provide a simple yet reliable method for wireless control and automation. Z-wave was developed by Zen-Sys and was later acquired by Sigma Designs. It is promoted by Z-Wave Alliance.The Z-Wave technology operates in sub-gigahertz frequency band i.e. around 900 MHz with a data rate up to 100 kb/s (9.6/40/100 kb/s with speeds being interoperable). Z-Wave is not an open standard but instead is a proprietary with Zen-Sys. Z-wave uses mesh network architecture with individual node range of up to 30 meters. Zen-Sys has announced a licensing program for Z-Wave that would allow other semiconductor manufacturers to produce Z-wave compatible devices [9]. Because of the absence of ubiquitous wireless devices in 900 MHz band, Z-wave seems comparatively less plagued from interference which is the problem with devices operating at 2.4 GHz band.

Insteon technology was developed by Smartlabs Inc. It is a home automation technology where devices interact with each other through powerline or Insteon Wireless network, or both. Unlike other technologies, Insteon uses dual mesh architecture in which all devices act as peers. Insteon devices can transmit, receive or repeat (only mains powered devices act as repeaters). Two protocols are followed [10]: Powerline protocol and RF Protocol. In Insteon, each message is simulcast by repeaters adding robustness to the network. Security in Insteon is provided by linking control (each device has its own unique ID) or through AES 256 encryption.

Standardized as IEEE 802.15.1, Bluetooth is a wireless ad-hoc point to point personal area network (PAN) technology [11]. Designed as low power technology, this wireless technology is especially useful in a home environment to interconnect intelligent appliances [12]. It could be suitably used for home automation in a cost-effective manner. Bluetooth operates in 2.4 GHz band providing a peak data rate up to 3 Mb/s. It uses Frequency Hopping Spread Spectrum (FSSS).

IEEE 802.11[4], also called as WI-FI is the standard for Wireless Local Area Network (WLAN). WI-FI is used to implement a cheap and open source home automation system. WI-FI is a power hungry technology, with receivers consuming over half a watt; thus battery powered WI-FI modules are rare. The range of WI-FI is typically 50 m (indoors) up to 100 m (direct LOS). Despite its high power requirements and complexity, WI-FI is a much reliable and performance impressive technology.
UWB (Ultra-Wide Band) is a high bandwidth high power and short-range personal area networking technology. UWB is potentially used in streaming media at home. There is no final UWB specification as various stakeholders are advocating for different kinds of protocol. UWB operates at an unlicensed spectrum of 3.1 to 10.6 GHz and hence is free from any jamming or interference.

Promoted by Wavenis Open Standard Alliance, Wavenis is the ultra-low power, long range wireless technology suited for machine to machine (M2M) applications. Wavenis supports mesh networking which is scalable to any size. Wavenis provides 2-way communication with complete application programming interface (API). Due to such low power consumption, Wavenis based devices have a multi-year battery life.

Other than these technologies many more technologies are available for WHAS. One of them is EnOcean. EnOcean is standardized as ISO/IEC 14543-3-10 for wireless applications involving low power technology that utilizes energy harvesting technology to draw energy from their surroundings – for example from motion, light or temperature differences. Thisallows EnOcean devices to operate without any external power supply. EnOcean devices operate at following frequency bands: 902 MHz, 928.35 MHz, 868.3 MHz and 315 MHz .It uses Amplitude Shift Keying (ASK) modulation providing a data rate of 125 kb/s spreading over the range of 30 m (inside) or 300 m (outside).

CONCLUSION

Although ZigBee has numerous applications, we focus our paper only on its application in WHAS. The main features of ZigBee were reviewed and also its technological specifications. A comprehensive survey on ZigBee-based WHAS is also reviewed along with some discussions on challenges faced by ZigBee and how these challenges can be overcome. The purpose of Wireless Home Automation System is to provide full control to the user in operating home appliances. Other than this, scalability, flexibility, easy implementation of smart homes are also important aspects that need to be kept in mind when implementing a technology. Based on the survey in this paper, ZigBee projects itself as a strong alternative technology in Home Automation. This paper also comparedvarious other technologies in WHAS with ZigBee. Some of the technologieslisted were Z-Wave, Insteon, Wavenis, UWB, Bluetooth, Since the minimum requirement to meet ZigBee and IEEE 802.15.4 specifications are relatively relaxed compared to other standards such as IEEE 802.11, it reduces complexity and cost of implementingZigbee. Thus, ZigBee protocol seems to be a good choice in implementing Wireless Home Automation System.

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