Design of ZigBee Device

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Abstract: - The paper describes early experiences with the new wireless communication standard ZigBee. The ZigBee is a low rate, low power wireless standard intended for automation, home controls and computer peripherals. The basics of the standard are explained and development of a ZigBee device hardware and software is described.

Key-Words: - wireless communications, industrial networks, smart sensors, wireless instruments, automation control, building control

1 Introduction

ZigBee is a new low rate wireless network standard designed for automation and control network. Expected applications for the ZigBee are building automation, security systems, remote control, remote meter reading and computer peripherals.

The ZigBee standard utilizes IEEE 802.15.4 [1] standard as a radio layer (MAC and physical layer). Three radio bands are defined (Fig.1 ZigBee standard variants):

- Global use: ISM 2.4 GHz band with 16 channels and data rate of 250 kb/s;
- USA and Australia: 915 MHz band with 10 channels and data rate of 40 kb/s;
- Europe: 868 MHz band with single channel and data rate of 20 kb/s.

The channels are numbered form 0 (868 MHz, direct sequence spread spectrum), 1 to 10 (915MHz, direct sequence spread spectrum) and 11 to 26 (2.4 GHz, offset-quadrature phase shift keying). The above mentioned data rates are theoretical. Due to the protocol overhead the actual data rates will be lower. A IEEE 802.15.4 packet has maximum length of 127 bytes including header and 16 bit checksum (CRC), where payload is up to 104 bytes. Some channels have recommended duty cycle restriction to achieve minimum conflicts among different ZigBee networks.

The IEEE 802.15.4 uses optional acknowledgement mechanism to achieve acknowledged transmissions if needed. However the acknowledgement is on the MAC layer only. The ZigBee stack or the application has to take care that all data received by the MAC layer will be processed. The acknowledgement mechanism takes care of repeated transmission if acknowledgment is not received within defined a time. If data fragmentation will take part in the data transmission further checksum control is needed to verify correct data reassembly.

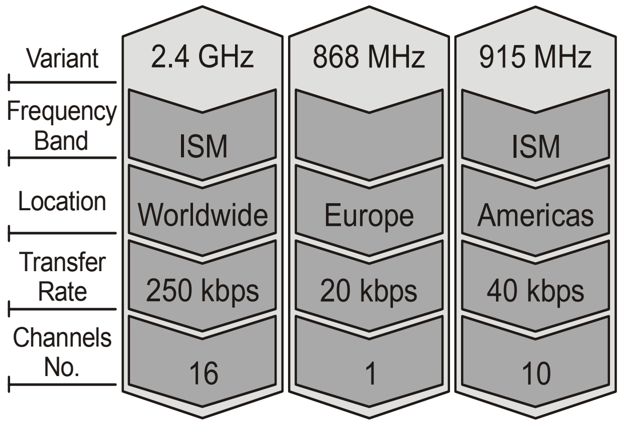

Fig.1 ZigBee standard variants

The ZigBee architecture recognizes two types of devices RFD (Reduced Function Device) and FFD (Full Function Device). Only a FFD can become a network coordinator. The RFD has limited firmware size and does not allow some advanced functions (e.g. routing) as it is a low cost end device solution. Each ZigBee network has a designated FFD which is a network coordinator. The coordinator acts as the administrator and takes care of organization of the network. Typical coordinator has a neighbor table of devices found in the neighborhood. If a device (orphan) intends to join an existing network it has to start network association procedure. First the device sends an authentication requested that is answered by the coordinator within a predefined time. If the device intends to rejoin a network, it has to start orphan notification procedure.

2 ZigBee Network

2.1 Network Configurations

The IEEE 802.15.4 [1] standard employs 64 bit (IEEE) and short 16 bit addresses. The short address supports over 65 535 nodes per network. The network identificator (PAN ID) is a 16bit number that is used to distinguish between overlaying networks. There can be 250 nodes per network and many networks located in the same area. To join a network the device has to know the PAN ID of the network it intends to associate. The IEEE 802.15.4 MAC enables network association and disassociation.

There is an optional superframe structure with beacons for time synchronization, and a guaranteed time slot (GTS) mechanism for high priority communications. The synchronization of the devices within a beacon enabled network is performed by the device by listening to the beacons transmitted by the coordinator. This enables the devices to sleep for long periods, as the beacons can be set between 15 ms and approximately 15 minutes and significantly help conserving power. In case of a network without beacons, the devices periodically poll the coordinator for data.

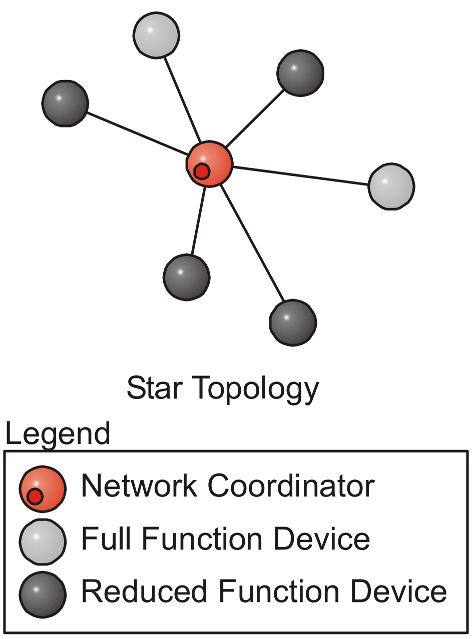

Fig. 2 ZigBee star topology

The access method is carrier sense multiple access with collision avoidance (CSMA-CA). The network coordinator makes decision to allows or deny the association of newly found device. If an overlay of networks with same PAN ID is detected the coordinator has to start conflict resolution procedure, which will guarantee that one of the coordinators will change PAN ID and/or channel and will also instruct associated devices to make the change too.

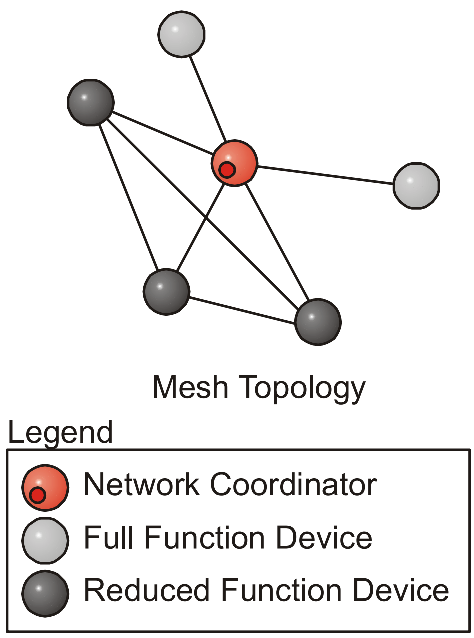

Fig. 3 ZigBee mesh topology

ZigBee supports either a single-hop star topology constructed with one coordinator in the center and the end devices (Fig. 2 ZigBee star topology). The devices in the star topology can only communicate via the network coordinator. The ZigBee also supports a mesh topology, sometimes called cluster-tree (Fig. 3 ZigBee mesh topology). Here the FFD devices in the network may communicate without the aid of the network coordinator. These nodes serve as routers in the network, forming a reliable network structure with healing abilities. The mesh networking is one of the key features of the ZigBee technology.

The multi-hop (Fig.3, 4) topology networks must support routing, so their network administration is more complex. At present most of the ZigBee stacks are preliminary and the support for multi-hop topologies is limited, but the base mesh functionality is usually supported.

The last possible ZigBee topology is tree (Fig. 4 ZigBee tree topology), which is a multiple star topology with one central node, the PAN coordinator.

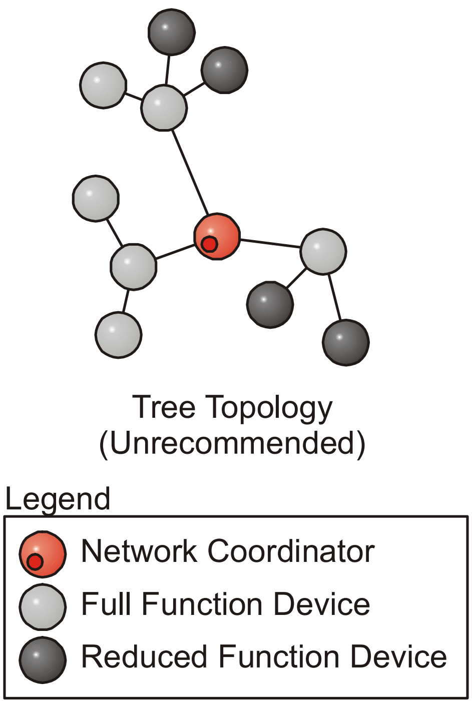

Fig. 4 ZigBee tree topology

The preferred topologies are the mesh and star. Mesh topology enables flexible network configuration and provides redundancy in the available routes. The star topology is necessary for RFD devices, as they are not capable of routing.

2.2 Data Transmission

ZigBee is a multiple access network with CSMA-CA access method. To allow for real-time transmissions the ZigBee there are defined two different data transmission mechanisms. In a non-beacon enabled network the standard CSMA/CA takes place. It means that any node may start the transmition at any time, as long as the channel is idle. It the beacon enabled environment the nodes are allowed to transmit in predefined time slots only. The coordinator sends a beacon frame (superframe) and nodes are expected to synchronize to this frame and send their data in a specific slot in the superframe. The superframe may have a special slot during which the nodes may compete using the CSMA algorithm.

2.3 Power Consumption

ZigBee is designed for applications that need to transmit small amounts of data while being battery powered so the architecture of the protocols and the hardware is optimized for low power consumption of the end devices. The coordinator and routing devices should not be battery powered as these should be able to receive and transmit all time, because the network functionality depends on this.
The data transfer mechanisms depend on the topology. In the simplest case, star topology, the end device (sender) wakes up from power saving mode, receives the bacon frame, sends data to the coordinator and goes to power saving mode again. The coordinator stores the data and once the other end device (receiver) polls for the data, the data are delivered. This method guarantees lowest possible power consumption of the end devices. The only disadvantage is that the coordinator has to be able to store all the data in its buffers, which might lead to large RAM needs.

3 Hardware Design of ZigBee Device

The challenge of battery powered ZigBee end device design lies in low power design of all electronics, utilization of power saving features of all components, efficient power supply design and design of radio frequency antenna part [3].

For the design of the ZigBee prototype a Panasonic PAN4450 module (Fig. 5 Panasonic ZigBee module PAN4450) consisting of Freescale HCS08 MCU and IEEE 802.15.4 radio MC13192 were used. Low power components for design of a micropower 2.8V power supply from ON Semiconductor were crucial to achieve projected mean power consumption in the order of 0,1 mW. Such low mean power consumption will enable to run an end device on single alkaline AA battery for more than one year.

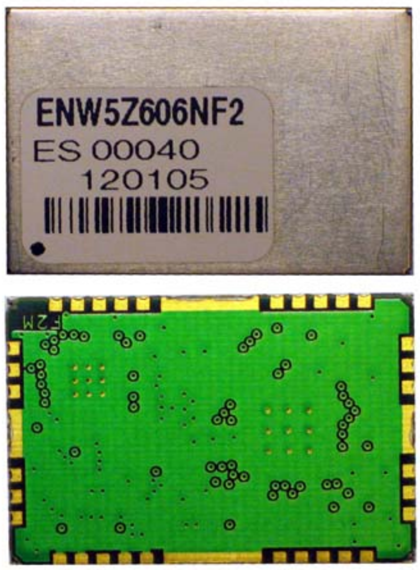

Fig. 5 Panasonic ZigBee module PAN4450

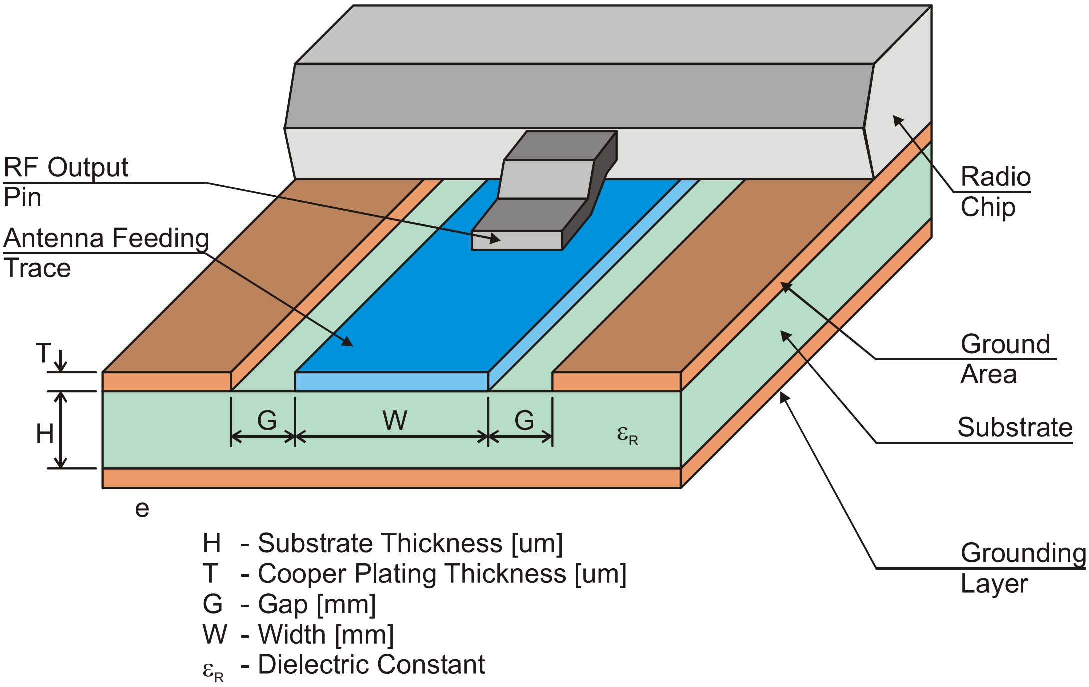

Fig. 6 Feeding line design

The radio-frequency part requires special care as at the frequency of 2.4 GHz the traditional low frequency design principles do not work. The antenna can be either chip antenna, PCB antenna as a trace on the PCB, or external antenna connected via SMA connector. In either case the feeding of the antenna has to be impedance matched so the high frequency properties of the PCB material have to be considered. The standard FR4 material has not guaranteed high frequency properties so quality PCB material (Taconic TLT) has been used for the RF part. For design of feeding lines (Fig. 6 Feeding line design) and/or antenna a loss and permittivity are crucial parameters of the PCB material.

Successful design of 50 ohm feeding line is difficult if the properties of the PCB material are not known. The standard FR-4 material either has unknown parameters at 2.4 GHz or the variation of parameters among manufacturers and even among batches from single manufacturer is regarded as significant.

In case of external antenna or chip antenna, the design of the feeding line is the only challenge with the PAN4450 module, because the module provides direct 50 ohm output. However, when designing the RF circuitry from scratch one has to add baluns for symmterization/impedance matching. As the MC13192 radio chip has separated transmit and receive lines if single antenna is required a 2.4 GHz switch is needed too.

The design of the radio frequency circuit is the most challenging part for designers who have no or little experience with the RF design.

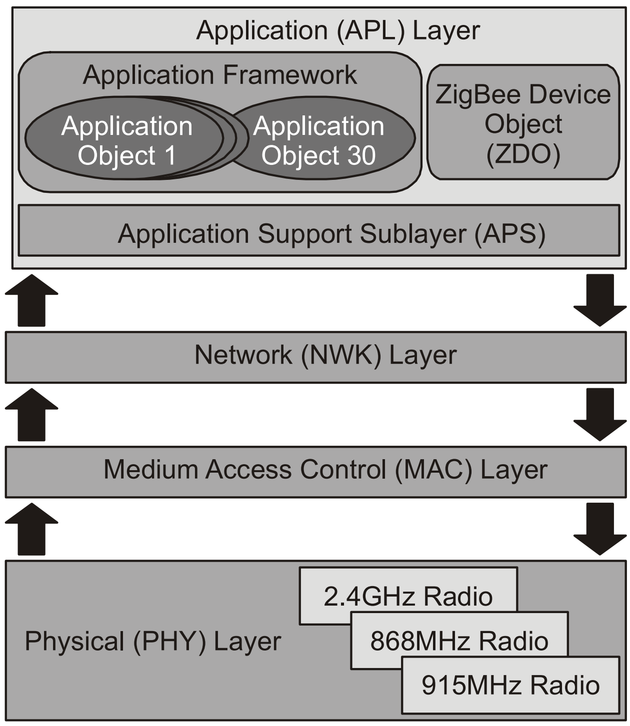

Fig. 7 ZigBee standard stack architecture

4 Software Design of ZigBee Device

The ZigBee stack forms the upper layers of the IEEE802.15.4 PHY and MAC sub-layer specifications [2]. It realizes the network layer (NWK) and in the application layer provides application support sub-layer (APS) and the ZigBee device object (ZDO). In the framework are added the user defined application objects. The structure is shown in Fig.7 ZigBee standard stack architecture.

The ZigBee application uses several principal terms, explained below. The *attributes* refer to some data that may represent a physical quantity for example. A set of attributes forms a *cluster*. The cluster and the address are used to look up a device. Each device is described by a *device descriptor* that is a description of the device within a specific application. *Endpoint* is a physical device identified by its address and supports applications with a single profile. *Profile* is a set of device descriptions forming a reasonable application. Every profile defines several device descriptions.

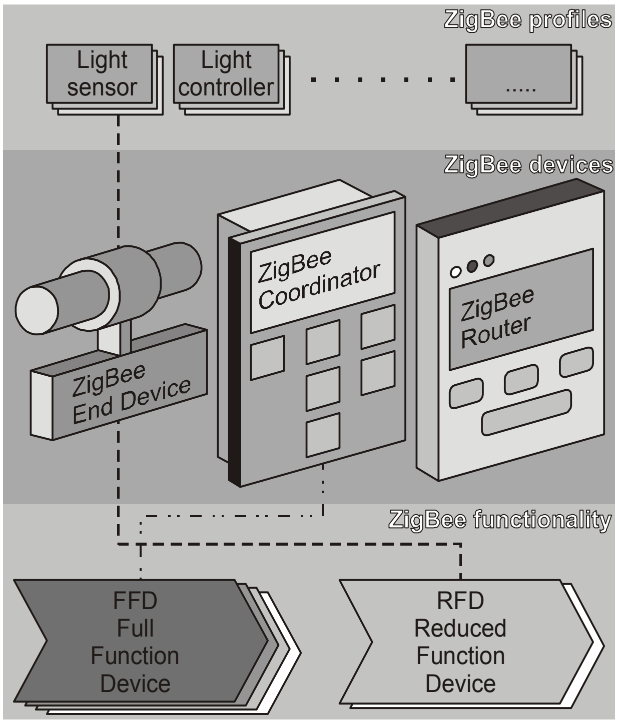

Fig. 8 ZigBee device type architecture

The available and proposed profiles are the Home controls, including profiles for lights control, heating and ventilation control, blinds and shades control. Safety devices include profiles for smoke sensor, CO_2 sensor. The Industrial control profiles will include device profiles for remote monitoring and simple control. Other profiles exist or being developed and it can be expected that there will be wide scope of available profiles to meet the most common applications.

The ZigBee device type is defined on several levels (Fig. 8 ZigBee device type architecture).

The physical device type can be a FFD or RFD. According to the node type within the network, the device can act as a network coordinator, router or end-device. And according to the profile, the ZigBee device will have a specific function, e.g. a light sensor.

5 Conclusion

The new ZigBee standard is progressive wireless communication standard, targeting automation and control applications. It provides reliable data transmission at low rates, with very low power consumption at very low-end device cost.

The paper described several principles and characteristics of the ZigBee standard hardware and software that were found necessary during the development of a ZigBee device.

6 ACKNOWLEDGEMENTS

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