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BLUETOOTH LOW ENERGY COMPARED TO ZIGBEE AND BLUETOOTH CLASSIC

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Bluetooth Low Energy compared to ZigBee and Bluetooth Classic.

Abstract

The thesis work is based on theoretical research and comparative analysis of the most remarkable short range wireless technologies as Bluetooth and ZigBee standards.

Nowadays two competitive technical standards approached a strategic aim. They both integrated customer's technical needs to have reliable, secure, low consumption and low cost technologies for controlling and monitoring applications with low data rate communication. Both technologies can be applied to serve a big variety of customer's needs and can be used in industrial sphere activity as well as individual.

Implementing the effective low energy consumption approach, devices demonstrate their operation on a single battery without charging for more then a year. They are almost similar to each other in the way of providing low power consumption. What technology provides the best lowest power consumption, Bluetooth or ZigBee? There is no certain answer. Consumers have to be more specific in technical aspects when they choose an appropriate technology. And understanding of the technical design would help to figure out which one of the technologies fits better for a wireless network area. In the near future, the current Bluetooth Low Energy standard will be the most needed as a standard is allowing both single and dual modes. This is an intermediate technology placed to support classic and new standard wireless devices in short-range wireless network.

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1   INTRODUCTION

At the dawn of the computer era people gave a birth to a new phenomenon of method of data exchanging in computer network. This is just a miracle of technology allowing two computers to exchange their data without wires. As we know, all wires and cables make a tangled mess. Since cables are no longer required we can transfer digital data more often. The modern market has a big variety of short length wireless technologies. In the world where communication networks become more complicated, there are more needs to use wireless connectivity between electronic devices instead of wires.

Bluetooth is a short-range wireless standard that allows connecting big variety of electronic devices together wirelessly. Especially the last Bluetooth Low Energy technology has remarkable an improvement so that theoretically it can connect endless number of devices. Nowadays the standard is very handy for users and can be found almost everywhere in a small environment like in your office, at home or even in your car. As many of us already have found useful the Bluetooth standard is very essential and convenient wireless technology to connect headsets, mobile phones, keyboards, computers etc.

It's already more than over ten years since first Bluetooth specification was officially realised. In nowadays the most of consumers and manufactures prefer the Bluetooth technologies more than others. There are many reasons, benefits for users to use the Bluetooth Technologies. Bluetooth is really quite simple and easy to use. It wouldn't be so popular if it wasn't easy to use. Many people believe that there is remarkable future for Bluetooth technology.
The wireless network technology is used in many purposes, has a variety of implementations in communication with mobile phone or computers.

In my diploma work I introduce classic Bluetooth technology compared to the last Bluetooth Low Energy technology and ZigBee lower consumption based solution.

The structure of study is as follows. The thesis is focusing on the unique characteristics of wireless networks. In Chapter 1 is an introduction, representing the basic under-

standing related to short-range wireless networks, and briefly describes their basic types.

In the Chapter 2, some background for the thesis is provided. In addition, some of the main characteristics of Bluetooth and wireless networks are given in the thesis.

In Chapter 3 describes the most interesting features of ZigBee standard. As well network protocols and interconnections between devices in a personal area network. In Chapter 4, the comparison between Bluetooth Classic and new standard Bluetooth low Energy is introduced.

1.1 Introduction to short-range wireless technology

1.1.1 Infrared

Infrared technology is the one of the most mature technologies. It has become extremely popular as an infrared data transmission technique for home computers, input devices like wireless keyboards and mice. Nowadays many computers come with IrDA ports which allow data to be transferred from another computer or mobile phones. They can exchange information with any computer or use a printer without any cable connection. Embedded LED is a light electronic component, emitting infrared wavelengths with very high brightness which have very narrow transmit beam. The element plays the most important role in transmitting process. In the simplest link of point-to-point data transmitting, most of the infrared light is directed from a source LED or semiconductor laser diode LD to photodiode which is called a detector. A transmitter converts an electrical signal to an optical signal. After captured optical light, detector converts optical power into electrical current. [URL2]

Some certain technical features precisely describe infrared technology. The best advantage is capability to carry a high bandwidth 4Mbit/s. Moreover a last infrared version supports data transmission between devices up to 16 Mbit/s. The high speed of the transmission is achieved using a protocol Very Fast Infrared (VFIR). From another point of view the main disadvantage is a nature of infrared energy. It is form of light which can be easily blocked and light can not pass through solid objects. [URL3]

Figure1 shows an electromagnetic spectrum for infrared signal. Infrared wavelength spectrum of the signal starts at the end of the microwave band and ends at the begin-

ning of visible light. The work interval of infrared wavelength is defined from 750nm to 1 mm. [URL1]

Figure 1. Infrared band in spectrum [URL4]

1.1.2 ZigBee

An interactive standard ZigBee was developed for applications that required a low data rate wireless networking, low battery power consumed and low running costs. However, the standard provides great flexibility compared to the other network types, with reliable and secure communication.

Most of modern wireless communications were developed as specially to meet the highest technical characteristics in order to achieve higher data transmission along with longer work distance. In fact such elements as sensors and controls of an active network don't really need to have high bandwidth but they definitely need very low battery consumption in order to save a battery power. A ZigBee 802.15.4 network is designed to communicate at 1 mW of radio frequency power. It is the standard tech-

nology which is addressed to applications like remote monitoring, control and sensor network functions for short distance communication. [URL5]

1.1.3 Ultra Wide Band

UWB is a wireless radio technology for transmitting data between consumer electronics, PC peripherals, and mobile devices within short range at very high speeds, while consuming little power. It is ideally suited for wireless transfer of high-quality multimedia content, such as wirelessly streaming family videos from the digital video recorder to a high-definition television in the living room.

UWB technology uses a wide band of the radio frequency spectrum to transmit data within a short range (such as in the home or small office), allowing for greater amounts of data to be wirelessly transmitted in a given period of time than more traditional wireless technologies. [URL6]

This is the next generation wireless connection. A difference between traditional radio transmission and UWB radio transmission is that traditional systems transmit by changing the power level, frequency and phase of sinusoidal wave. UWB transmission transmits data by generating radio energy at specific time instant moments and occupying large bandwidth by using a large part of radio band. Ultra Wide Band technology include systems are using signals with a bandwidth of 500 MHz. Wideband (UWB) signals are very short pulses and duration of such signals is less than a few units of nanoseconds. [URL7]

1.1.4 Wireless USB

Wireless USB is a high-speed wireless interconnect application that take advantage over UWB technology. The Wireless USB technology has many advantages compared to other wireless technologies. It also takes all benefits to provide the same usage and architecture as wired USB.
The Wireless USB Promoter Group, of which Intel is a leading member, is defining the wireless USB specification as a high-speed bidirectional connection. [URL8]
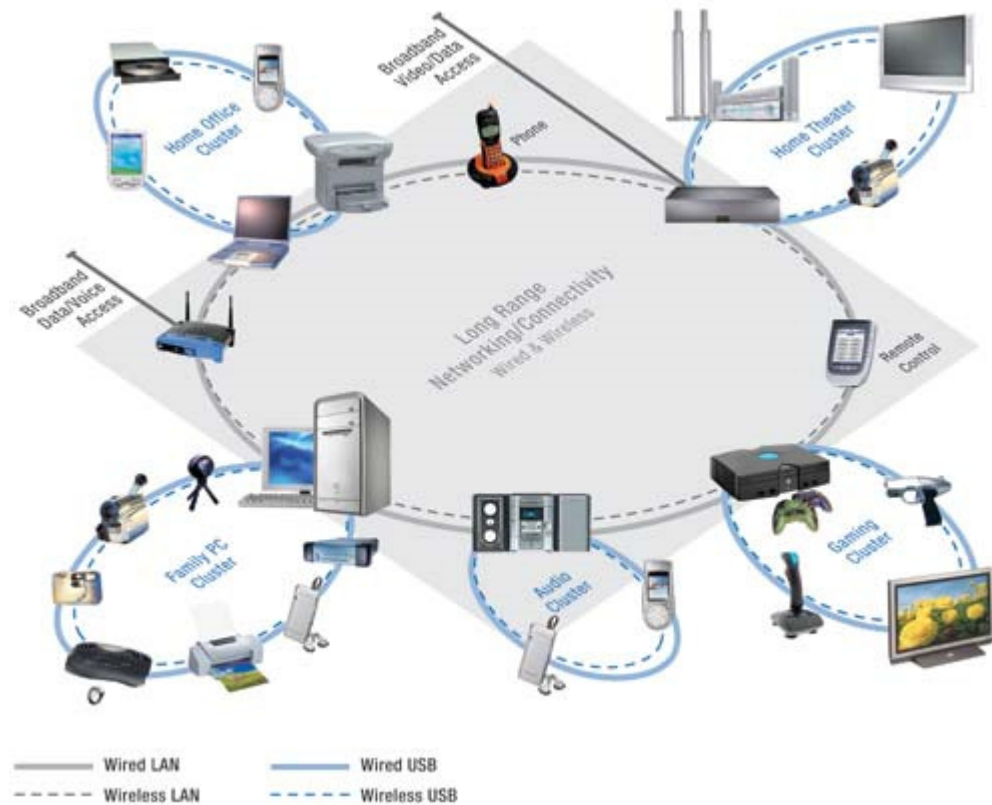
Figure 2. Consumer Usage Models [URL8]

1.2 Standard IEEE 802.15

Working Group IEEE 802.15 is developing 802.15 standards for wireless personal networks (PAN) and coordinating them with other group of standards, such as the 802.11 standard for wireless local area network.

1.2.1 Standard groups

Working Group IEEE 802.15 has series of the following groups such as:
802.15.1. Working Group 1 specifies standards for wireless personal area network, is originally based on the use of the Bluetooth version 1.1. The basis of this technology is spread-spectrum frequency hopping (FHSS), speed does not exceed 1 Mbps.

802.15.2. The team responsible for the development of this standard, the Working Group 2, gives practical advice to facilitate the coexistence of networks standards 802.15 and 802.11. The problem is that both networks operate in the same range of 2.4

GHz, therefore coordination between their work is vital. The Group assesses the potential interference and suggests methods to counteract them.

802.15.3. Working Group 3 is working on new standards for high-speed wireless personal networks. Data rate may be varied from for data transmission is 11 up to 55 Mbps. Along with this elevated rate of transfer standard gives effect on the mechanisms to guarantee communication quality of service (QoS) which makes the standard a good basis for the work of multimedia applications such as television and digital cameras. This group is also concentrating to reduce lower cost and power consumption.

802.15.4. Working Group 4 is working on standards providing a low data rate, but at extremely low power consumption for small devices designed to work without replacing the battery for months and even during years. Objects for the application of this technology can be all sorts of sensors, "smart" identification badges and the system of home automation but it does not support voice communication operating at 2.4 GHz Data transfer rate is 20, 40 and 250 kbps. [URL63]

1.3 Summary of technologies

The following Table 1 gives a main comparison to the low power wireless technologies presented below. Bluetooth wireless takes a first place in the short comparison. Definitely, in future design development with its major price advantage there is no doubt that Bluetooth LE will keep the top position over the wireless technology of the others. Since there are not so many developments are done in the area of wireless communication, so Bluetooth can pretend to monopolize the wireless network on short range with the new low power technology is implemented into devices. And it is just only a matter of time when the technology becomes as a popular technology.

Table 1. Short-range Wireless Technologies

Type	Work distance	Data Rate	IEEE standard	Modula-tion	Applica-tions	Cost
Infrared	Very short	Up to 4Mbps	IrDA	ASK PPM	Remote controls, PC, PDA, phone, lap-top links	Ultra low
UWB	10-30m	480Mbps	IEEE 802.15.3	OFDM or DS-UWB	Transmis-sion of video/ audio data	Low
Wireless USB	3-10m	From 110 Mbps to Hi-Speed 480 Mbps	IEEE 802.15.3	MB-OFDM	Digital media, high data stream	Low
ZigBee	From typ.10 to max.100 meters	20 kbit/s (868 MHz) 40 kbit/s (915 MHz) 250 kbit/s (2.4 GHz)	IEEE 802.15.4	BPSK (868 / 915 MHz) OQPSK (2.4 Hz)	General use Remote control, battery-operated products, sensors	Ultra low
Bluetooth Classic	10 meters	From 1Mbps to 3 Mbps	IEEE 802.15.1	GFSK, PSK	General purpose, cable replace-ment	Low
Bluetooth Low Energy	10 meters	1 Mbps	IEEE 802.15.1	MB-OFDM	At sports, health, and consumer electronic applica-tions	Low

2 INTRODUCTION TO BLUETOOTH CLASSIC

2.1 About the Bluetooth SIG

Bluetooth as a name of a technology has a huge historical background from the 10th of century Danish King Harald Blåtand or Harald Bluetooth in English. More than a thousand years after the death of the Danish king, the company Ericsson Mobile Communications has established a research group to study the possibility of using radio waves to provide interaction of different devices at short distances. When the Swedish company is satisfied by results of the research work, the representatives of Ericsson applied for cooperation with other firms. Before, in 1998 the five companies as Nokia Corporation, International Business Machines Corporation (IBM), Intel Corporation, Toshiba and Ericsson Corporations have organized a group of Special Interest Group (SIG), which was actively engaged in the development of Bluetooth standard.

Nowadays Bluetooth is a well known trademark of Bluetooth Special Interest Group, the group of leaders in the telecommunication systems, computing technologies, consumer electronics, automotive and network industries, actively working on the development of standard Bluetooth and bringing it to word market. The technology is already has accepted by over then 2100 companies around the world.

Figure 3. Bluetooth logo [URL10]

2.2 Bluetooth wireless technology

Bluetooth technology is world leader and the most successful short range wireless communications technology to support both voice and data transmission to create a personal area network. Many chips are imbedded into huge amount of technical devices beginning from cellular phones, headsets and stereo headphones, through to medical devices, portable media players and games consoles.

At every beginning the main idea for Bluetooth technique was that it has to have a universal radio interface is connecting to different devices communicating to each other and provides low cost wireless communication that uses radio technology. Bluetooth devices are very good solution for applications especially when designers need low power consumption, excellent performance, and minimum size.
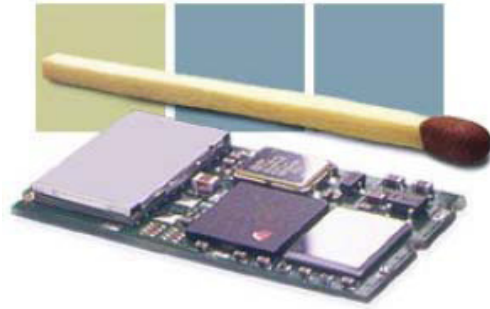

Figure 4. A single-chip size [URL13]   **Figure 5. Bluetooth Devices [URL17]**

Bluetooth connects huge amount of devices allowing them to use a high-speed, low-power wireless link technology. It is designed to automatically connect portable equipment together when one Bluetooth device on a work distance to another device with the same standard. The network protocols are able to provide secure, reliable connectivity of transferring a user voice, required data with a very flexible network topology. Totally different from infrared technology the Bluetooth does not require direct positioning of light to the units. The most notable that the radio chips are very small and can fit in any electronic device. In Bluetooth communication a user doesn't need to be involved in process of establishing communication. Dynamically the Bluetooth devices enable every time constantly send address information and establish network between devices.

2.3 Radio Frequency hopping

The work frequency for Bluetooth devices operates globally around the world.
This is the licence free frequency band at 2.45 GHz open to any radio system.

The frequency range differs from rules of a country where Bluetooth device is used. For United States, Japan and Europe the unlicensed range has certain limits from 2,400 MHz to 2, 483.5 MHz if the transmitting power exceeds 0 dBm.

However some European countries still allow a part of the whole spectrum, only 23 channels are available for transmitting in France, Japan and Spain.

Geography	Regulatory Allocation	Blue Tooth Channels
USA	2.400 – 2.4835 GHz	f = 2402 + k MHz k = 0…78
Europe	2.400 – 2.4835 GHz	f = 2402 + k MHz k = 0…78
Spain	2.445 – 2.475 GHz	f = 2449 + k MHz k = 0…22
France	2.4465 – 2.4835 GHz	f = 2454 + k MHz k = 0…22
Japan	2.471 – 2.497 GHz	f = 2473 + k MHz k = 0…22
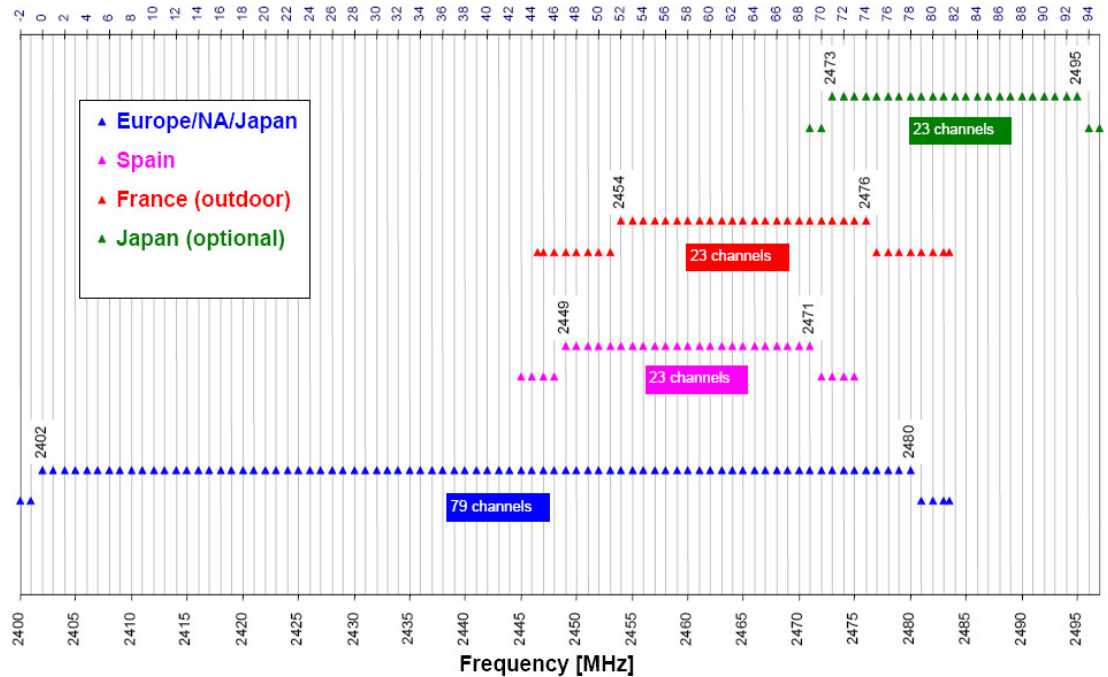
Figure 6. Spectrum allocations [URL15]

Bluetooth is using frequency-hopping spread-spectrum technology (FHSS). Frequency hop technique divides the whole frequency spectrum into several hop channels with nominal bandwidth 1 MHz for each channel. During a connection Bluetooth transceivers use all 79 channels and rapidly hop from one channel to another in random manner across all the channels. Every channel is divided into time segments, slots with

duration 625 µsec. All slots are numbered in the range from 0 to 2^{27} -1 and in accordance with the clock master piconet. Transceiver is using only one channel at a time.

When one device is connected to another Bluetooth device, it hops with hop rate of 1600 hops per second and lingering with a residence time 625 µsec on any randomly given frequency channel. A device can not be operating more than 0.4 second within any 20 second period for frequency hopping systems operating in the 902–928 MHz band. In the 2400–2483.5 MHz band the average time of a channel is not more than 0.4 seconds within a period of 0.4 seconds multiplied by the number of employed channels. The restrictions are applied by FCC regulations to limit interference in the unlicensed industrial, scientific and medical (ISM) band. [URL16]

2.4 Transmission protocols

2.4.1 Frequency-hopping spread spectrum

Frequency-hopping spread spectrum (FHSS) is well-known one of the main modulation method of digital coding. In FHSS transmission technology the original signal is converted into another signal so that the signal transformation becomes more like the noise for a random device.

The technique of coding increases the number of transmitted bits and expands the bandwidth of a signal. FHSS transmission technology spreads energy in the time domain by dividing the spectrum into a number of channels. FHSS system transmits a narrow band signal and rapidly changes frequency from one to the next frequency and spending a few milliseconds for each frequency.

Switching between frequencies in a pseudo random sequence during transmitting data needs to be synchronized. The synchronization will need much more power in FHSS method compare to direct-sequence spread spectrum (DSSS). The method is used in Bluetooth. [URL21]

FHSS uses a narrowband carrier that changes frequency in a frequency order that is well-known to both transmitter and receiver. They are both hopping between frequen-

cies and transferring a piece of data on the same pseudorandom pattern during each hop. The transmission frequencies are determined by hopping code.
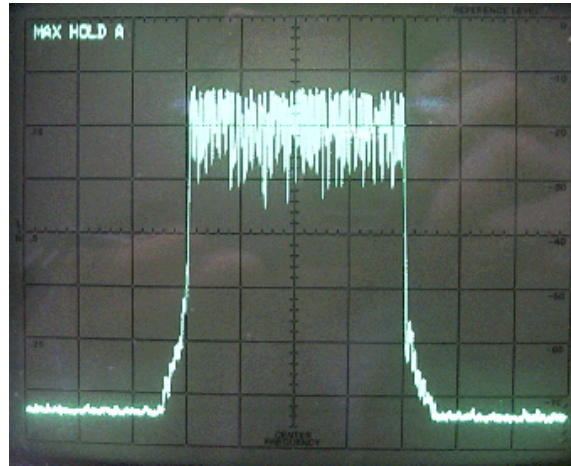

Figure7. Spectrum for 3 Mbps FHSS for the 2400-2483.5 MHz band [URL20]

However, interference does not break a connection. A benefit of FHSS is that the order of frequencies can be adaptive. Adaptive hopping can help to avoid frequencies that probably can be blocked by high interference level.

Frequencies and order in which they are used in a hopping pattern and dwell time are restricted. For example, for operation 2.4 GHz band in America the FCC, Federal Communications Commission requires that 75 or more frequencies be used with a maximum dwell time of 400 milliseconds. If noises or errors occur on one current frequency more the time is allowed to be at each frequency. In this case it hops on another frequency with the order in which they are used. Then data will be retransmitted immediately. [URL64]

2.4.2 Direct sequence spread spectrum

DSSS is wideband modulation with direct extension of the spectrum, is one of the three main methods of spread spectrum used for nowadays. It has a remarkable property of digital communication that secure communication channel from interception, interference and eavesdropping of a signal. That is why this technology was originally developed and used for the U.S. Armed Forces. The system transmits on a single frequency but on very wide bandwidth. The information has originally a narrow band-

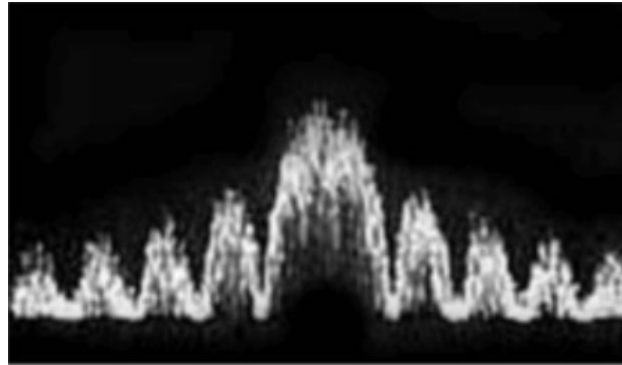width but it is divided on a wide bandwidth in the DSSS process. The method is used in ZeegBee [URL37]

Figure 8. Spectrum-analyzer photo of a DSSS signal [URL37]

DSSS transmits a signal, which occupies a very wide bandwidth. In a DSSS process, a narrow-band signal is multiplied by a high-speed sequence of pseudo noise numbers (PNs) to get a spread signal. Each PN pulse is called a chip or chipping code. If signals care a different code than original code as a result of radio interference then receiver will filter out rest of signals. A receiver can recognize only the same code. The result of multiplication of the received signal and the signal of the same source of pseudo random noise compresses the range of useful signal and increases the spectrum of background noise. The larger the expansion of the spectrum brings the better signal's resistance to interference. This allows the system to operate at the level of interference. Even if one or more bits in the chip are damaged during transmission, the original data can be recovered because of the redundancy by using statistical techniques without the need for retransmission. [URL40]
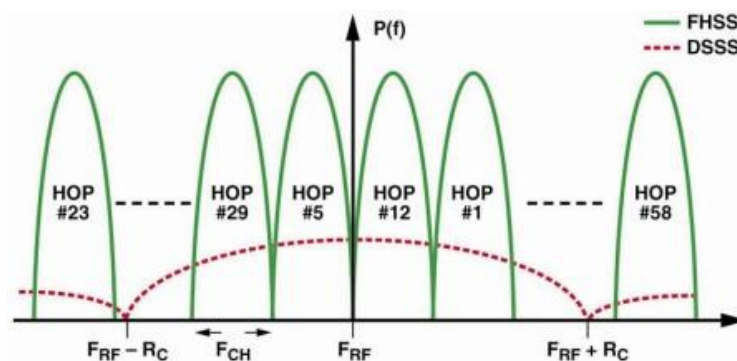

Figure 9. Frequency spectra for FHSS and DSSS [URL41]

Data transmission between low-power devices are not interference with normal radio systems. They have narrowband high-power and practically do not create interference with broadband because of high power signals make "noise" within limits of narrow channel and can not suppress entire broadband signal. [URL41]

2.5 Time Division Duplex

The Bluetooth specification uses Time Division Duplex (TDD). One channel is divided into sequence of time slots. Each slot represents duration of short time 625 µsec in length for a single-slot packet.
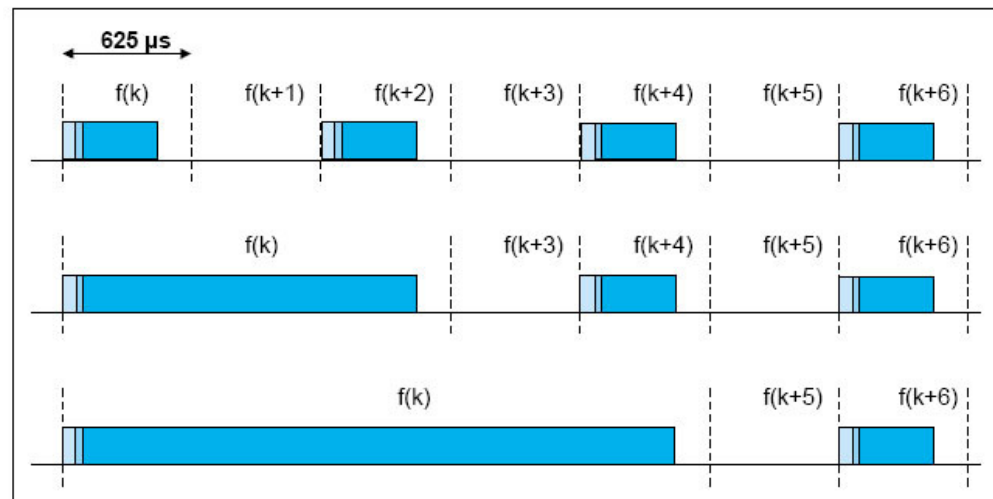
Figure 10. Single and multi slot packets [URL19]

On a given channel for transmitting or receiving only one packet can be transmitted per slot. If happened so, that a transmitted packet was not accepted during transition. A receiver informs system and the package will be resend on the hop channel with another frequency.

All connections use TDD because it provides good connectivity, more flexiblity in transmitting the data in bi-directional way of communication. For instance when we are browsing web-sites the user sends a small data to the server but the server will send larger amount of data in response. Time Division Duplexing allows uplink and downlink to share the same spectrum of frequency. It helps to use an available spectrum more efficiently. When we have many data to download we can give more time-

slot to download and less for upload. And it is controlled dynamically as a more efficient way during non-equal transmission.

Of course a usage of the same frequency channel for uplink and downlinks makes the construction of antennas, transmitters, receivers and whole base station equipment simpler. Another reason that TDD can be used for Bluetooth devices because TDD standard can handle a big amount of customers at one time but by using the standard we can cover big communication area.

2.6 Orthogonal Frequency Division Multiplexing

OFDM or Orthogonal Frequency Division Multiplexing is a special type of multicarrier modulation. It is some kind of a replacement of a single high frequency carrier by multiple sub carriers that are used for one transmission link between two stations. Transmitted data stream is distributed over large number of channels and the data is sent over all the channels simultaneously.
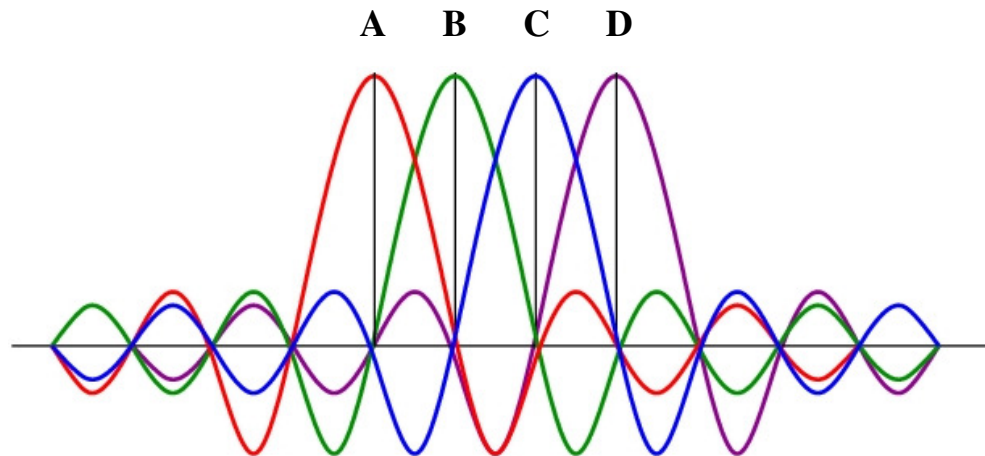
Figure 11. OFDM frequency channels [URL50]

High speed is the advantage of the simultaneous data transmission even if transmission rate on every channel is not so high. Independent to each other sub channels have very tight frequency intervals between them in order do not make frequency interference.

As shown on the Figure 11, sub channels overlap each other because of the form of the carriers are orthogonal makes frequency spectrum in more efficient way. [URL49]

2.7 GFSK Modulation

Gaussian frequency shift keying (GFSK) modulation is used in low data-rate wireless audio, video transmission as well as in personal communication standards like Bluetooth.
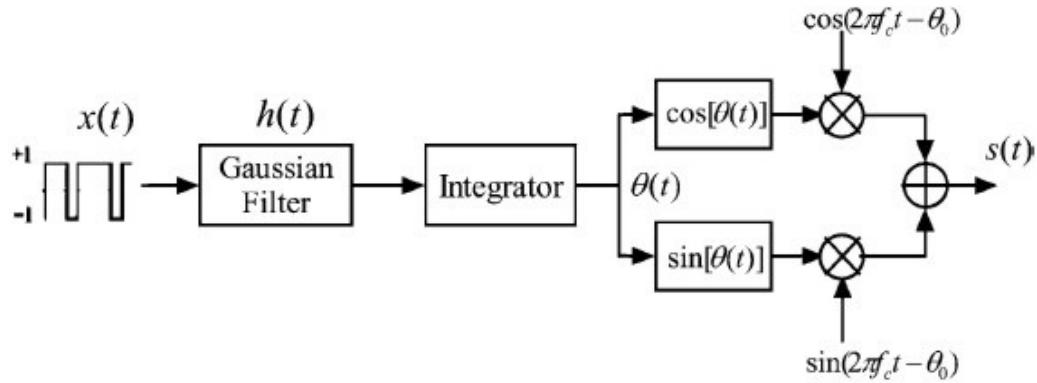
Figure 12. Functional scheme of GFSK modulator [URL43]

Classical Frequency Shift Keying with Gaussian filter called GFSK. On Figure 12 is shown how a bit stream passes through Gaussian filter which has better performance for smoothing sharp transitions. The input signal is first filtered by the Gaussian filter and then modulated by the frequency generator consisting of an integrator.

Gaussian filter provide an effective narrowing of the bandwidth by smoothing the sharp transition voltage and good control over Gaussian parameters. [URL43]

The impulse response of the Gaussian filter can be expressed in mathematical form as:

$$h(t) = \frac{1}{\sqrt{2\pi}\sigma T} \exp\left(\frac{-t^2}{2\sigma^2 T^2}\right)$$

where $\sigma = \sqrt{\ln(2)}/2\pi BT$.

Figure13. Gaussian filter output equation

2.7.1 Modulation characteristics

Bluetooth technology uses Gaussian frequency shift keying modulation index from 0.45 to 0.55. Binary unit corresponds to a positive frequency deviation, and a binary zero corresponds to a negative frequency deviation. If -1 use for Ft-fd and 1 for Ft+fd so when -1 state changes to 1 the modulated signal changes immediately state too.
It is important to limit the spectral occupancy of a signal, to improve bandwidth efficiency and remove adjacent channel interference.

Binary symbols are transmitted at a frequency of 1 MHz ± 20 ppm. For each channel, the minimum value of frequency deviation (Fmin = min {Fmin +, Fmin-}) for a sequence of characters in 1010 should be not less than 80% of the frequency deviation (fd) for a sequence of characters 00001111. The minimum deviation should never be less than 185 kHz.
Unwanted frequency of random deviation of the transmitted signal must be less than 8% of the period of wave on Figure 14. The problem rises from many reasons like the instability of parameters, their changes of the numerical values during the transmission and different transmission rate of the frequency components of the same signal.
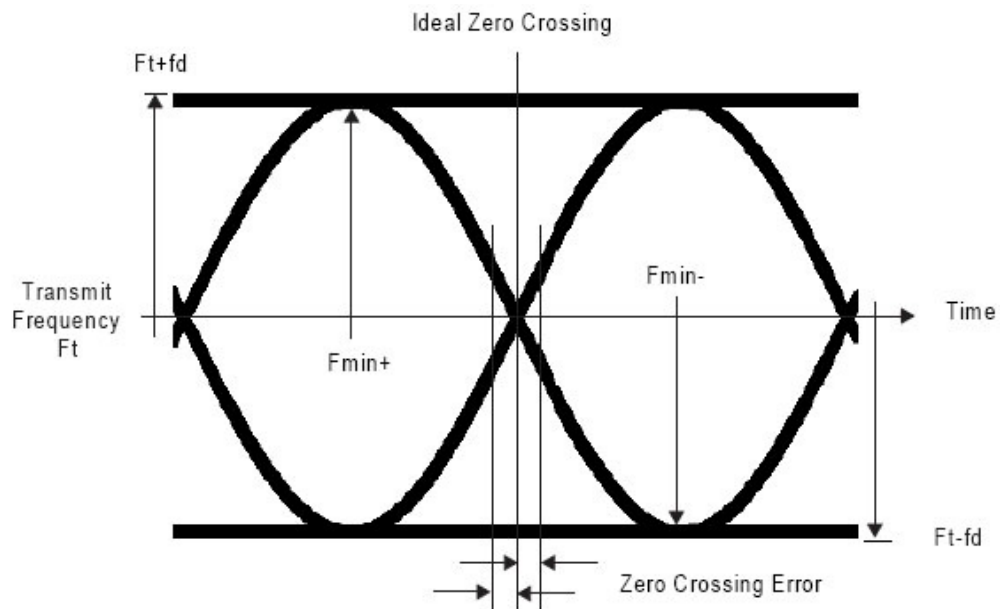[URL44]

Figure 14. GFSK parameters [URL44]

2.8 Bluetooth network topology

The typical Bluetooth network topology is based on two main net concepts such as "Piconet" and "Scatternet". Bluetooth protocol can support connection between one or more Bluetooth devices by simply using concepts of two networks.

When piconet includes only two connected devices, the net refers to point-to-point connection scheme or other specific scheme as point-to-multipoint net with more then one slave devices connected together. One or more devices create a piconet if they are synchronized on the same physical channel.

In the Bluetooth network two types of connection are possible: synchronized or asynchronous connection. Synchronous Connection-Oriented (SCO) is used for point-to-point connection and more orientated to establish connection which usually used to transmit voice packets or mixed voice and data packet. Asynchronous Connectionless (ACL) supports point-to-multipoint connection without establishing connection between devices. And supports symmetric and asymmetric connections point-to-multipoint packet-switching, which are commonly used to transmit data.

Configuration	Max. Data Rate Upstream	Max. Data Rate Downstream
3 Simultaneous Voice Channels	64 kb/sec X 3 channels	64 kb/sec X 3 channels
Symmetric Data	433.9 kb/sec	433.9 kb/sec
Asymmetric Data	723.2 kb/sec or 57.6 kb/sec	723.2 kb/sec or 57.6 kb/sec

Table 2. SCO and ACL supported data rates

All devices in a piconet hop together. Piconets are not synchronized to each other and every piconet has their own sequence of frequency-hopping.

In a typical piconet only one of devices works as a master and rest of them act as slaves. Actually there is no limit in number of slaves. Master can connect 7 is the maximum number of active slaves connected simultaneously. But if there are more that seven, rest of the slaves must be "parked". Amount of parked slaves can be up to 256 per piconet. Every parked device gets direct an 8-bit Parked Member address.

(PM_ADDR). Any parked device is synchronized by master clock can quickly change their current state to the active state and get 3-bits Active Member address (AM_ADDR). Below examples of Scatternet [URL22]
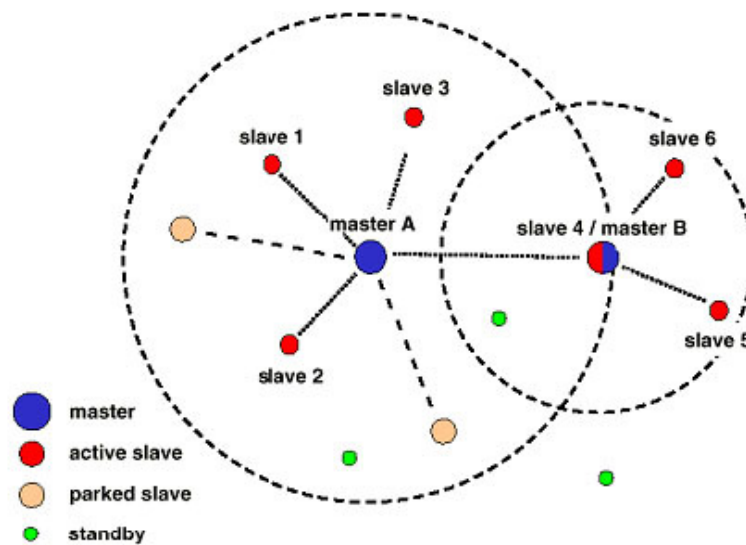
Figure 15. Scatternet [URL23]

As an example user case demonstrating the need for a clean, high quality implementation of scatternet is shown in Figure 3.5. Here is a user synchronizing calendars between a phone and a notebook PC while at the same time carrying on a phone conversation using a Bluetooth headset. In this case the mobile phone acts both as a master towards the headset and as a slave towards the computer. The appropriate scatternet topology would be the most appropriate in order to have uninterrupted connection and effective data speed.

Figure 16. Example of scatternet user case. [URL14]

2.9 IEEE 802.15.1 protocols

2.9.1 Bluetooth protocol architecture

Standard ISO resents a valuable approach in understanding the standard as a unique method of an interaction between devices. It explains networking rules how data should communicate inside of a system. ISO has seven layers that define a networking framework. Here, it will be more discussed the Transport Layer as a required part of Bluetooth technology and it has the same traditional OSI PHY and MAC components are shown on Figure 17.

There are four basic protocols that all Bluetooth devices have to implement. They are Baseband, Link Manager Protocol (LMP), Logical Link Control and Adaption Protocol (L2CAP) and Service Discovery Protocol (SDP). [URL25]
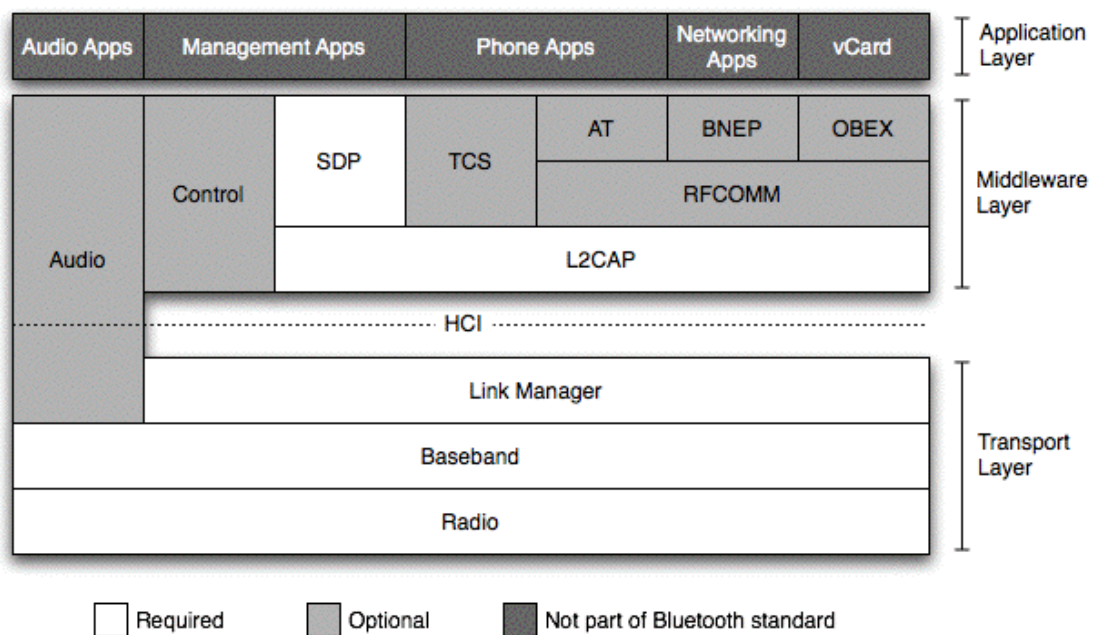

Figure 17. Bluetooth protocol architecture [URL24]

Describing the above architecture of Bluetooth protocols consisting of several main protocols are:

- Radio layer is designed to transmit and receive packets on the physical channel. The layer defines frequency details and employs frequency hopping,

modulation scheme. Bluetooth devices operate at 2.4 GHz unlicensed band frequency reserved for general use by ISM applications.

- Baseband is responsible for how Bluetooth devices connect to other device. The layer supports SCO, synchronous data packets for voice and asynchronous ACL type of links for data transmission. Here a packet processing defines type of the packages, their transmission and retransmission, addressing and power control.

- Link manager protocol (LMP) controls the size and timing of packets. Responsible for link setup between Bluetooth devices, it includes security procedure such as authentication and encryption.

- Logical link control and adaptation protocol (L2CAP) – provides an adaption of upper-layer protocols to the baseband layer. Some higher layers use packets with a bigger size than Bluetooth can work with, so the packets have to be segmented into several data portions going down the stack. L2CAP reassembles packages when they're going through to pass up the stack. The protocol provides both connectionless and connection-oriented services.

- Service discovery protocol (SDP) is the part of Bluetooth that provides information about services. It lets to find a device or browse through the list of services are offered for users. [URL65]

3 ZIGBEE TECHNOLOGY

ZigBee operates over the same 2.4 GHz frequency range as Bluetooth Classic and Bluetooth LE. Unlike those technologies, though, ZigBee transmits at much lower data rates. It's made for sending simple commands, such as turning on a TV, or small bits of data, such as whether a door is locked.

The low data rate of ZigBee takes far less power than other networking technologies. That's why battery life of a ZigBee device can often be measured in years, rather than hours or a few days in the case of Bluetooth.

3.1 Introduction to ZigBee

ZigBee is a well-known registered trademark of the ZigBee Alliance. This trademark is registered in certain countries only.

Figure 18. ZigBee logo [URL25]

The ZigBee alliance includes such companies as Invensys, Honeywell, Mitsubishi Electric, Motorola and Philips.
Primarily ZigBee takes its name from zigzag path of bees. ZigBee technique is similar to the bee dance as a way to share information as the location, distance and location of a new found food source to other members of the colony. They easily can apply mesh network topology to share information between flowers. Embedded network devices are like bees and can communicate, share the information between nodes. [URL 28]

3.2 Technology Overview

ZigBee Technology is flexible and multi purpose standard designed for wireless controls and sensors. Because of the ZigBee applications operate with low data rate there

are no needs for high bandwidth. It is necessary need for low latency and to establish reliable power-saving local area network for sensors and control devices. The most attractive feature is that ZigBee technology allows devices to communicate with one another with low power consumption technique which allowing permanent usage of a battery even for years.

ZigBee is based on the synchronization mode, in which the slave network devices, most of the time are in "sleep" state, to periodically "wake up" them to receive the synchronization signal from the network coordinator. It allows devices to know a moment of time when they can transfer data. The mechanism is based on determining the state of the communication channel before transmission, can significantly reduce (but not eliminate) collisions caused by the transfer of data simultaneously multiple devices.

The main advantage from customer point of view is the smaller memory size requirements to implement the entire protocol as a result it makes a reduction in cost. There are many wireless systems that require low cost, current drain and do not require high data rates. ZigBee is the technology providing a standardized base set for application requirements. [URL27]

The underlying 802.15.4 standard provides strong reliability through several mechanisms at multiple layers. For example, it uses 27 channels in three separate frequency bands.

Figure19. ZigBee frequency bands for communications [URL26]

The 2.4 GHz band is used worldwide and has 16 channels and a maximum over-the-air data rate of 250 Kbps. Lower frequency bands are also specified. The 902–928 MHz band serves the Americas and much of the Pacific Rim, with 10 channels and a

burst rate of 40 Kbps. European applications use one channel in the 868–870 MHz band, which provides 20 Kbps burst rate. This rich assortment of frequencies lets applications with the appropriate hardware configuration adjust in real time to local interference and/or propagation conditions. Once on a specific channel, the 802.15.4 radio relies on a number of mechanisms to ensure reliable data transmission, including binary phase shift keying (BPSK) in the 868/915 MHz bands and offset quadrature phase shift keying (O-QPSK) at 2.4 GHz.

3.3 Network Topology

Star, mesh, cluster tree are three different topologies are all supported by ZigBee. The figure below shows good examples of ZigBee network topology where star and mesh topologies represent multiple path communication between devices. The most useful topology for end devices is a star topology. When several end devices are located close to each other they can communicate with a single router. As well as the same node can be a part of more complicated mesh network topology that communicates by the network coordinator. And very network has to have coordinator device as a necessary part of network. Actually network coordinator is the device responsible for managing for information about each node and information transmitted or received over network. Mesh topology is more reliable compared to other topologies as specially in case when one node goes down and mesh networking allows finding alternative path to continue transferring data. [URL29]
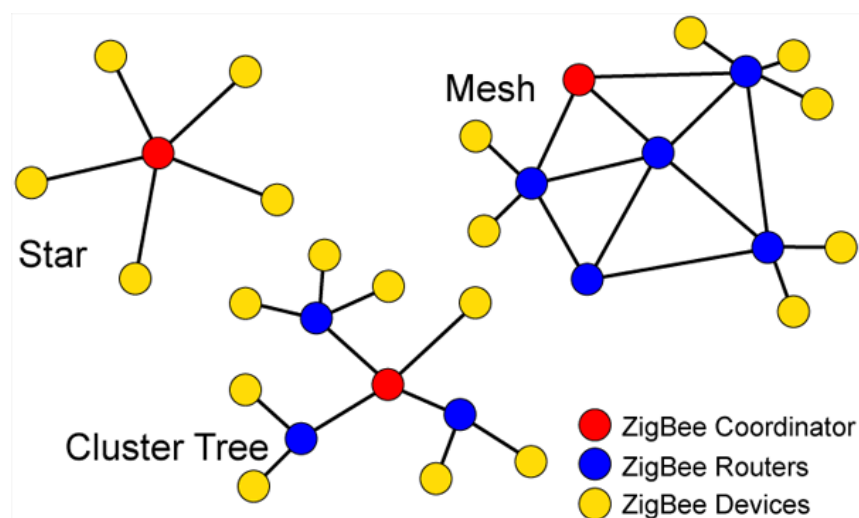

Figure 20. ZigBee network topologies [URL26]

3.3 The IEEE 802.15.4 Standard

ZigBee is the technique built on using the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard. The IEEE is a non-profit organization unites members and volunteers are working to develop IEEE 802 wireless standards. Well-known Bluetooth standard is also a part of the IEEE 802 standard family. So for the IEEE 802 working group it is necessary to ensure that all the standards can coexist and operate in the same radio space.

IEEE 802.15.4 is a standard as Wireless Personal Area Network, characterized by low cost of the components, reduced coverage area, low power transmission, bit rate and energy consumption. IEEE 802.15.4 is based on half-duplex data transmission. It means that a device can transmit or receive data within PAN. In this case CSMA-CA method can be used to prevent collisions but not for detecting them.
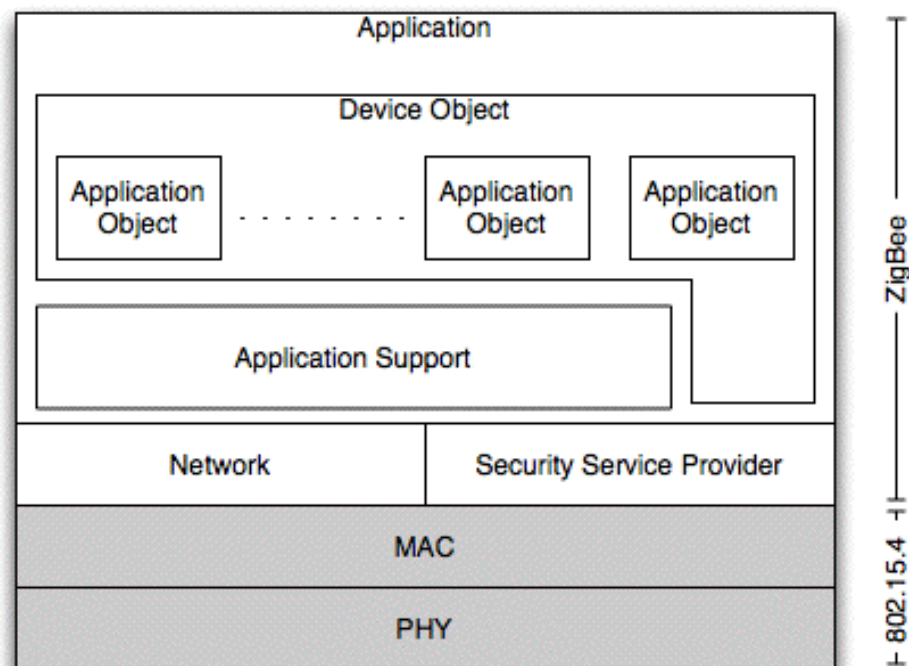
3.5 ZigBee Layered Model

Figure 21. ZigBee Protocol Stack [URL24]

In fact, IEEE 802.15.4 standard is a physical radio or radio transceiver chip. ZigBee is a logical network and software stack provides security and routing functions and multi-hop transmission for creating more complex topologies.

On the Figure21 is clearly shown structure of ZegBee protocol Stack. Here, 802.15.4 standard adopts two lower level stacks: level of media access (MAC) and physical layer data (PHY). Upper layers of the stack describe ZigBee standard. Including both layers the devices establish interconnection within personal area network (PAN). The layers were designed to handle a big amount of nodes per network.

3.5.1 PHY Layer

PHY layer is responsible for radio communication of transmitting and receiving data along with its low-level control mechanism, determining number of channels, operating frequency range, modulation tape and maximum speed. The layer makes the transceiver to be active or deactivate when it goes in sleeping mode. The layer has been designed for BPSK modulation 868 MHz band in Europe has 1 channel, 20 Kbps, the 915 MHz band in North America, Australia has 10 channels, 40 Kbps. 2.4 GHz band is band accepted in almost all countries which has 16 channels, 250 Kbps in O-QPSK modulation. [URL32]
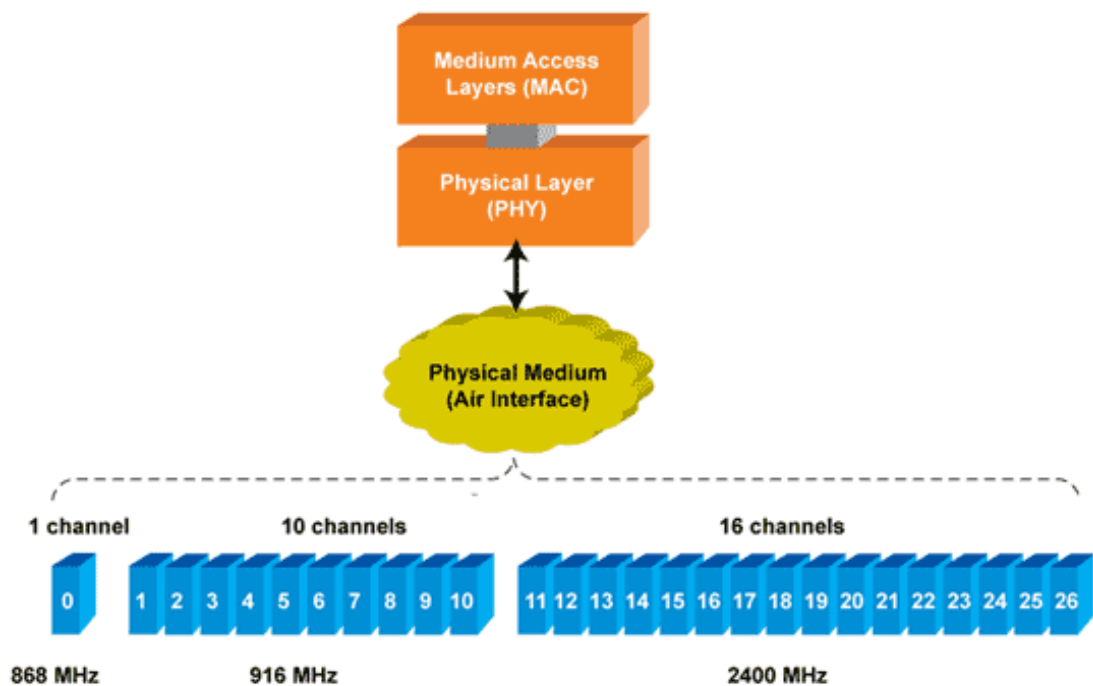

Figure 22. RF bands and channels in IEEE 802.15.4 standard [URL33]

3.5.2 MAC Layer

The Medium Access Control Layer (MAC) layer provides access to the physical chan-nel. This is the next level in the structure of ZigBee stack. MAC is responsible for providing input and output of the network devices, defines reliable network communi-cation and provides efficient usage of limited channel bandwidth between a node and its neighbours.

MAC layer supportes main tasks are described below:

• Data framing

 Before transmission MAC layer encapsulate data into a MAC frame and send it to node. The node accepts only frames addressed for it. Then, received frames are un-packed and checking for errors that can occur during transmission.

• Device addressing

Every device has a unique 64 bits long MAC layer address which is used to indentify devices. Sender sends the address as destination for packets sent on the MAC layer.

• Employ CSMA/CA mechanism

Carrier Sense Multiple Access with Collision Avoidance is well known "listen-before-send" principle. This is the one of the main task is to avoid collisions among multiple devices by listening shared frequency channel for when the channel is free for trans-mission. This is known as CSMA/CA mechanism for transmitting data. [URL32].

• Device Association and Disassociation

Upon higher layer requests MAC layer performs device association and disassociation, when a device enters or leaves network.

• Sending acknowledgement frames

Used for confirming successful frame reception

3.5.3 MAC frame structure

MAC command frame is handy to bring MAC address commands to destination device. There are four types of frame structures help in device communication:

- A beacon frame, used by a coordinator to transmit beacons

- A data frame, used for transferring of data between devices

- An acknowledgment frame is used for confirming successful frame reception in a time of message acknowledgment connection

- A MAC command frame is used for handling all MAC peer entity control transfers. [URL66]

Frame format is composed of three basic components: MAC header, MAC payload, and MAC footer.

Octets:	1	0/	0/2/	0/	0/2/	Variabl	2
Frame Control	Sequence number	Destinatio n PAN	Destinatio n	Source PAN Identifier	Source Address	Frame Payload	Frame Check Sequence
			Addressing			MAC Payload	
			MAC				MAC Footer

Figure 23. General MAC frame format [URL52]

The MAC header includes frame control and address fields. The 16 bits frame control has to have number of subfields as frame type, source and destination addresses, frame pending, ACK request and Intra PAN.
Frame type of field is mentioned as Frame control field has a description what kind of frame is sent to destination addresses Beacon, Data, Acknowledgement or MAC command.

MAC footer field contains a 16-bit frame check sequence (FCS). Check Sequence field contains four check bytes. It lets for receiver verifies that the packed was received without detected errors in the data carried in the frame.

The MAC payload field is optional and has variable format, its size varies from 0 till 104 bytes more than enough to meet sensor requirements. [URL54]

Command frame identifier	Command name	RFD Tx	RFD Rx	Subclause
0x01	Association request	X		7.3.1
0x02	Association response		X	7.3.2
0x03	Disassociation notification	X	X	7.3.3
0x04	Data request	X		7.3.4
0x05	PAN ID conflict notification	X		7.3.5
0x06	Orphan notification	X		7.3.6
0x07	Beacon request			7.3.7
0x08	Coordinator realignment		X	7.3.8
0x09	GTS request			7.3.9
0x0a–0xff	Reserved			—

Figure 24. MAC commands [URL55]

MAC command frame is the frame to carry MAC commands to prospective device. The command frame identifier identifies the MAC command being used. As shown on Figure 24 describes list of command names. For Reduced Function Devices (RFD) there are still some limitations. Full Function Device (FFD) is able to transmit and receive all the command from the list of MAC commands.

3.5.4 Beacon frame format

The order of beacon frame format has to be in the same keeping order as a structure of general Mac frame format. The main structure of beacon frame is shown on Figure 25 below. Beacon frames are used by coordinator and periodically transmitting to the network by coordinator's request. They are used to wake up devices that are not in active condition.

Octets:2	1	4 or 10	2	Variable	Variable	Variable	2
Frame Control	Beacon Sequence Number	Source Address	Superframe Spec	GTS Fields	Pending Address Fields	Beacon Payload	Frame Check Sequence
MAC Header			MAC Payload				MAC Footer

Figure25. Beacon frame format [URL52]

Beacon frames bound every single Superframe from both sides with purpose of communicational synchronization.

The beacon MAC header frame is sequent order of Frame Control field, Sequence Number field, Source Address field. Here, in the Frame Control contains a value that corresponding to the value of tree zeros are indicating a beacon frame state. The addressing field consists of some source address only is an appropriate address for network coordinator which sends beacon frames for activation of the network device.

The Superframe Specification field this is 2 octets or 16 bits field specifies different parameters of Superframe. It determines duration and active portion of Superframe interval. It lets to know if the frames are transmitted by coordinator or by some other device has a request and possibility to connect new devices to the current network.

The GTS field contains variable of bits in length, it activates the number of devices that has guaranteed time slots GTS. Amount of the devices can be up to seven. The devices which are very sensitive to data transmission time a GTS descriptor list describes a short address, starting slot and duration of appropriate GTS. It also defines one of the two transmission directions allow sending data from device or get connection to device.

The Pending Address fields consists an address of network device that has a pending data in coordinator. When network devices receive a beacon from coordinator they will look at the pending address in order to see if there are some data waiting are ready to be transmitted.

The last beacon field as Field Check Sequence is used by receiver to check any possible errors in the receiver fame. [URL56]

3.6 Superframe structure

Superframe is limited by two network beacons. Its duration consists of 16 slots with the equal size. Coordinator determines the structure of super frame and can allow or terminate usage of Superframe by not transmitting the beacons. First slot of super frame is always transmitted in the first frame.
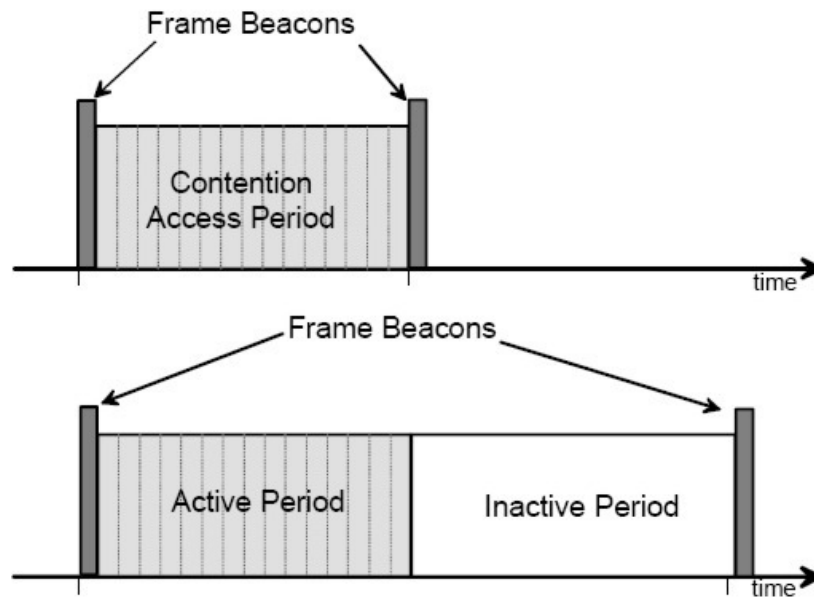
Figure 26. Superframe structure without GTS [URL36]

Most of the time network devices are in a sleeping mode and periodically they wake up to get a synchronization signal from coordinator or according to CSMA-CA protocol. It allows devices to be informed when following data transmission is going to be. Coordinator conducts data exchange, assigns channels and call devices at a certain interval from 15ms to 252 sec. Scheduled sending those signal packages gives better capacity and low latency to get access.

Superframe may have an active and an inactive portion, but Superframe doesn't include an inactive portion in Superframe duration. The inactive period is necessary to realize low energy consumption mode when batteries are used as the main power supply for devices. During the period will be no beacon transmissions.
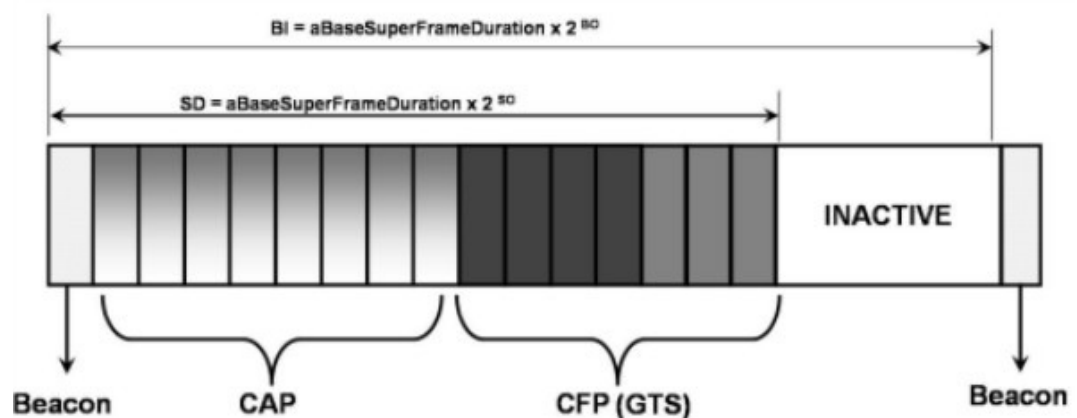

Figure 27. Superframe structure with GTS [URL35]

For those applications which require speed and higher data transmission the coordinator can locate up to seven guaranteed time slots (GTSs) after contention access period (CAP). During that period devices are guaranteed to send or receive urgent data. The GTSs form content of CFP which is always situated at the end of Superframe. [URL69]

3.7 ZigBee main modes

Depending on network communication ZigBee operates in one of two main modes in MAC layer, known as non-beacon mode and beacon mode. These modes enable data traffic to or from network device. Coordinator always has to have well source of power supply in order to provide uninterrupted network activity. To perform a maximum power savings the beacon mode is used when coordinator device runs on batteries. Otherwise is wise to use the non-beacon mode when power supply is constant or can be applied to inactive devices in network, which always in sleep mode.

Beacon mode is based on CSMA/CA and schedules the network access with an imposed time-slot allocation. Another non-beacon mode is used a pure CSMA/CA protocol.

In beacon mode, the coordinator periodically is transmitting a beacon to the device in stand by mode. Coordinator's beacon wakes up each device and the device must determine if it has any addressed messages. If no messages or message transmission is complete the device returns "to sleep" as well as the coordinator switches into stand by mode too. There is certain time scheduling for the next beacon and all devices know when coordinate to each other. Even wake up earlier from sleep mode in order do not to miss a next beacon.
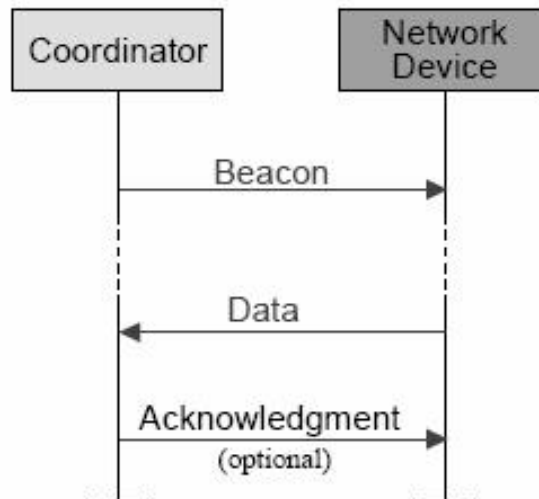
Figure 28. Beacon Network Communication [URL31]

Non-beacon mode is less coordinated network and any device can communicate with the coordinator in its own schedule. Coordinator must always be listening for signals that are coming from device after random period of time. Because of the power consumption of network devices is low for such devices like smoke detectors or alarm systems which are inactive long period of time that gives a big advantage for usage ZigBee technology. For coordinator it is necessary to have more power supply to be ready for unscheduled device interaction. However, in this mode when a channel is busy different devices can cause collisions within the network. [URL31]
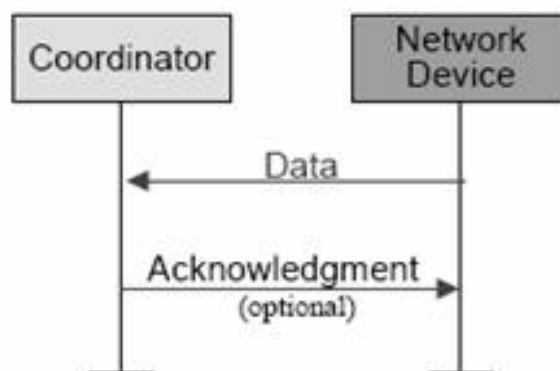

Figure 29. Non-Beacon Network Communication [URL31]

3.8 Device Association and Disassociation

Association is the process to make device to join a network. Mac provides whole association process to network layer (NWK). There are four association commands to establish connection.

In order to join coordinator's network a device sends MLME-Associate.request that device wants to connect with coordinator. MLME-Associate.indication is used to inform NWK layer of coordinator to know about request. After waiting certain period of time the device receives MLME-Associate.response and at the end of the association process MAC passes a confirmation MLME-Associate.confirm to the NWK layer. After all, the device is become as an associated device.

When an associated device intends to leave coordinator's PAN the device has to have a disassociation procedure. A device has to send MLME-Disassociate.request in order to disassociate device. There are can be a few reasons, it might be so a coordinator wants to leave PAN or device wants to leave.
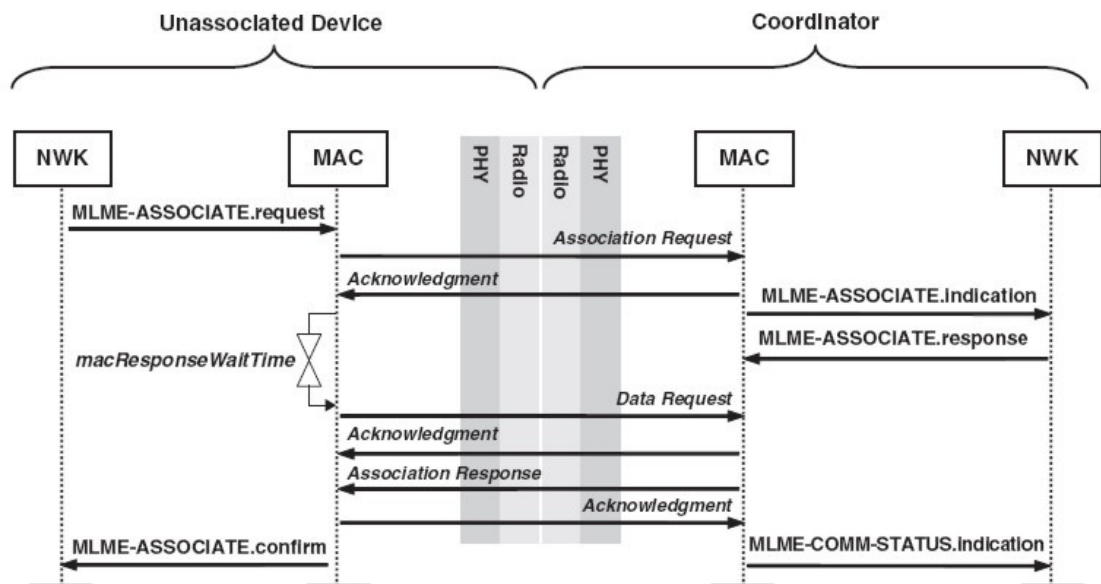

Figure 30. Device Association and Disassociation [URL39]

3.9 CDMA-CA

Carrier Sense Multiple Access with Collision Avoidance is used in wireless systems for determining the state of communication channel before transmitting. In a case when one device intends to transmit data to another device in the same time, the situation can cause a collision. Devices detect a jam signal and have to wait random period of time before starting to send data again. We need to apply a polite contended method which can avoid collisions. There is handshake method to deal with that kind of collisions and negotiate a transmission between devices. CSMA/CA mechanism can reduce but not eliminate collisions completely.

IEEE 802.15.4 is based on half-duplex data transmission. It means the device can either transmit or receive data that allows using the method CSMACA to prevent conflicts rather than to detect them. [URL51]

3.10 BPSK versus O-QPSK

3.10.1 Binary Phase Shift Keying

ZeegBee technology is using both BPSK and O-QPSK modulation methods for IEEE 802.15.4 standard. Physical layer uses Binary Phase Shift Keying (BPSK) at frequencies of 868/915 MHz and Quadratic Phase Shift Keying with an offset (O-QPSK) at a frequency of 2.4 GHz. They are both modulation using the Direct Sequence Spread Spectrum (DSSS) access mode.
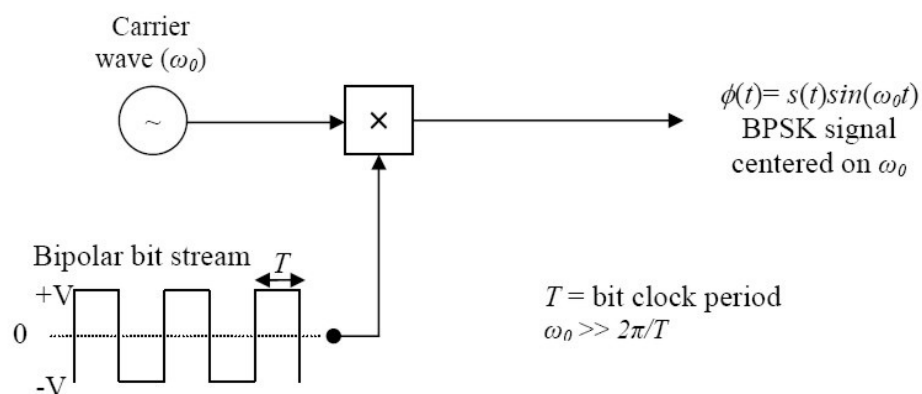
Figure 31. Generating BPSK [URL45]

One of the simplest types of digital modulation is called two-position or binary phase shift keying (BPSK). The phase values of carrier signal moves between 0 and 180 degrees in accordance with digital bit stream. Non-return-to-zero-mark (NRZ-M) digital coding is used in BPSK.

Phase modulation can be done in two different ways. As mentioned above, the initial value of the phase can take two values 0 and 180 degrees. In this case, for the implementation of phase modulation like as a frequency modulator, it requires two generators of signals. Both the generator should generate the same frequency, but with different initial phase.

In the next method, the phase modulation considered as a variant of amplitude modulation with an active pause. The amplitude signal takes two values -1 and +1. This is equivalent for changing the phase by 180 degree. Each time when the bit stream changes values of the signal from -1 and +1 by crossing zero level, the phase of the PSK signal also changes its value. A value "1" makes a phase transition and "0" do not make any transaction at all.

Using BPSK as a binary phase modulation we can send a normal binary signal. Symbol rate of this type of modulation is 1 bit per symbol. [URL46]
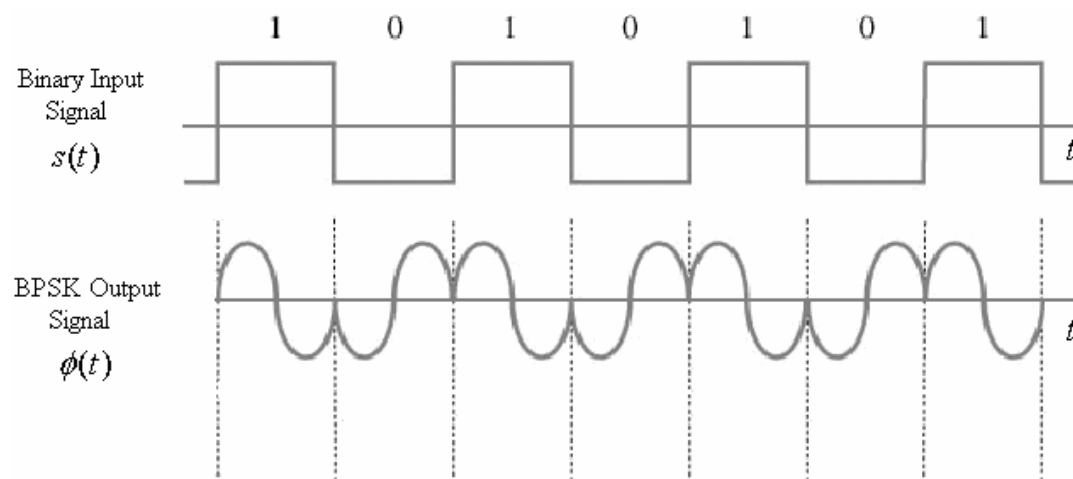

Figure 32. Input Signal and BPSK Output [URL45]

Offset BPSK is more stable to interference and less efficient in transmitting data over device connection with less bandwidth provides for transmission. The transmission provides 40 Kbps as a maximum data rate 40 Kbps with frequency for 915 MHz and 20 Kbps for 868 KHz.

3.10.2 Offset Quadrature Phase Shift Keying

OQPSK is short name for Offset Quadrature Phase Shift Keying. It is more effectively using a spectrum of frequencies for transmitting data compared to BPSK modulation. Below on the Figure 33 a modulating block diagram makes sequence of two bits in a symbol.
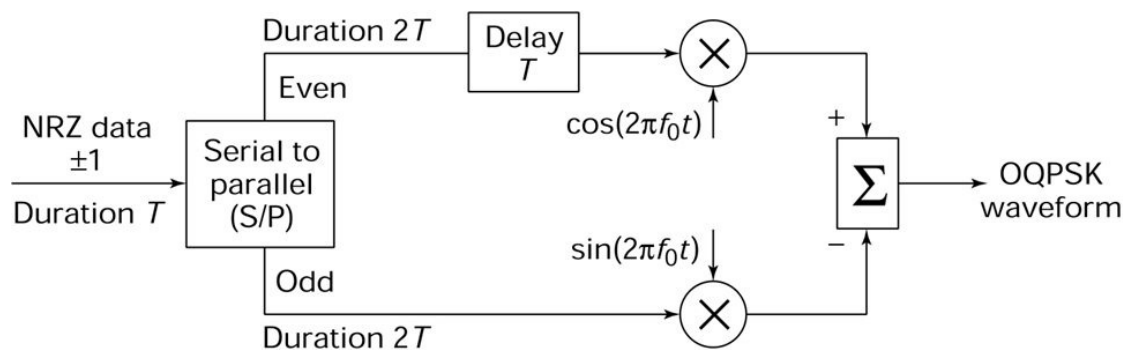
Figure 33. Block diagram of the OQPSK modulator [URL47]

OQPSK does the splitting of a data stream mk(t) into an I-Phase stream mi (t) and a Q-Phase, quadrature stream mq(t). Q and I streams are In the Q-OPSK system a modulated signal has four different phase values of RF carrier. In means that the phase of signal taking four phase values change every 90 degrees and change the state every Tb period. In order to organize an offset between signals Q-Phase and quite similar I-Phase, it is necessary to make Tb delay. Because the form of the modulation during one symbol interval transmits two bits of input bit stream at once. Symbol rate of the type of modulation is half a symbol per period.

Figure 34. Offset QPSK Pulse waveforms [URL47]

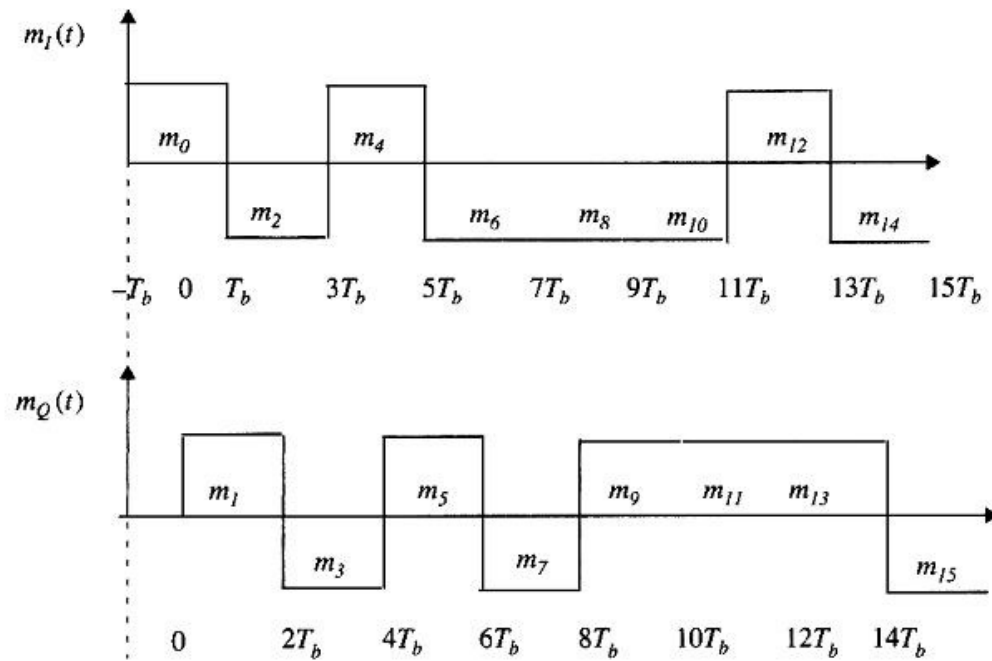Offset O-QPSK is more efficient in transmitting data over device connection. Instead of sending 1 or 0 every time with every single phase, it can carry in two times more information in the same amount of time. The modulation technique provides higher data rate with bandwidth in 2.4GHz frequency band has maximum data rate 250 Kbps. [URL70]

3.11 Typical Applications

According to designed ZigBee protocols have a variety of solutions are using for embedded applications. It solves the most important needs for consumers which always would have reliability, affectivity, low-energy consumption and low cost. ZigBee meets all the requirements to be so popular for home general proposes, collecting medical data as well as industrial control needs. ZigBee devices can interact without wire and be simply controlled from remote control or even cell phone. Because of the ZigBee technology was designed so it doesn't consume a big amount of energy. This is a very remarkable feature for complicated networks when network devices do not need to change power systems for years. ZigBee can be used in many cases. The current applications cover almost all areas in our busy life. [URL48]
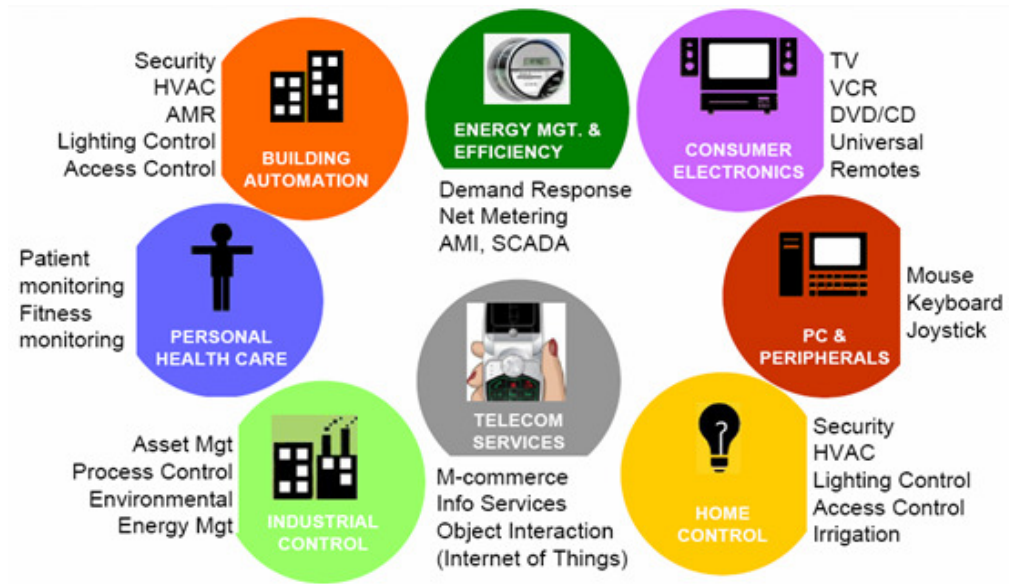
Figure 35. ZigBee applications [URL48]

Health Care gives opportunities to wireless sensor technology for specific collection of personal data. Depending on individual health status it can provide permanent and frequent measurements or part-time monitoring, notify immediately when a patient has a critical state. Non medical monitoring provides collection of environmental, motion and home monitoring. All data from devices will be analyzed and secure forward for storage. For example, another promising area to use the sensor control can decrease a individual risk during personal sport training and schedule each train according to gathered information. Personal Fitness Monitoring where the information can be displayed and send for record keeping. [URL67]

4 BLUETOOTH TECHNOLOGIES VERSUS ZIGBEE TECHNOLOGY

4.1 Introduction to Bluetooth Low Energy

Bluetooth low-power technology is the next generation of wireless standard from the Bluetooth Special Interest Group. Technically the new Bluetooth design is modified from previous technical design. Part of existing Bluetooth design was improved to enable a new technical version of low energy consumption which provides a new technical support for a new set of applications.

Distinctive feature of Bluetooth LE is an implementation of two types of device. They are called single mode and dual mode devices. The single mode supports only Bluetooth low energy and consumes less power than previous devices. And single mode devices can not talk directly to classic, regular Bluetooth devices. In a dual mode application chips support both Classic and Bluetooth Low Energy where battery energy consumption is optimized for long time usage more than one year. Dual type devices are expected to replace Bluetooth old devices to the new low energy standard within next few years. And single mode devices are going to be a new type of equipment that requires much lower power consumption than regular Bluetooth. [URL57]

4.2 Enhanced Bluetooth standard

BTLE or Bluetooth Low Energy makes definitely some important changes compared to classic Bluetooth. First and the most remarkable feature is longer battery life of Bluetooth devices especially in time when the system does not send a lot data between nodes.

In fact, the implementation of low power consumption makes a change to Physical Layer and packet format in order to reduce power. That is why classical or regular Bluetooth devices can not communicate to BTLE without implemented dual mode.

All the modes make the new technology of devices unchangeable and unique for classic and BTLE interconnection. It means that hundreds of millions of devices as mobile phones, PCs, MP3 players and so on can communicate to BTLE devices. [URL58]

The technology is designed to operate in globally accepted and license free 2.4 GHz frequency with 1 Mbps bit rate over a distance of 5 to 15 meters.

Compared to Bluetooth Classic the new technology performs better in following characteristics:

- Provide ultra-low-peak, average and idle mode power consumption
- Run a standard battery for years
- Ability to have multi user interconnection
- Provide a better coverage for users
- Be inexpensive

4.3 Bluetooth LE consumption

Bluetooth LE protocol was optimized for low power when we have small amount of data. It means that the protocol is more effective for short packets with ability for small amount of data to transmit as well in case when a device is not transmitting the data has being optimized heavily compare to regular Bluetooth.
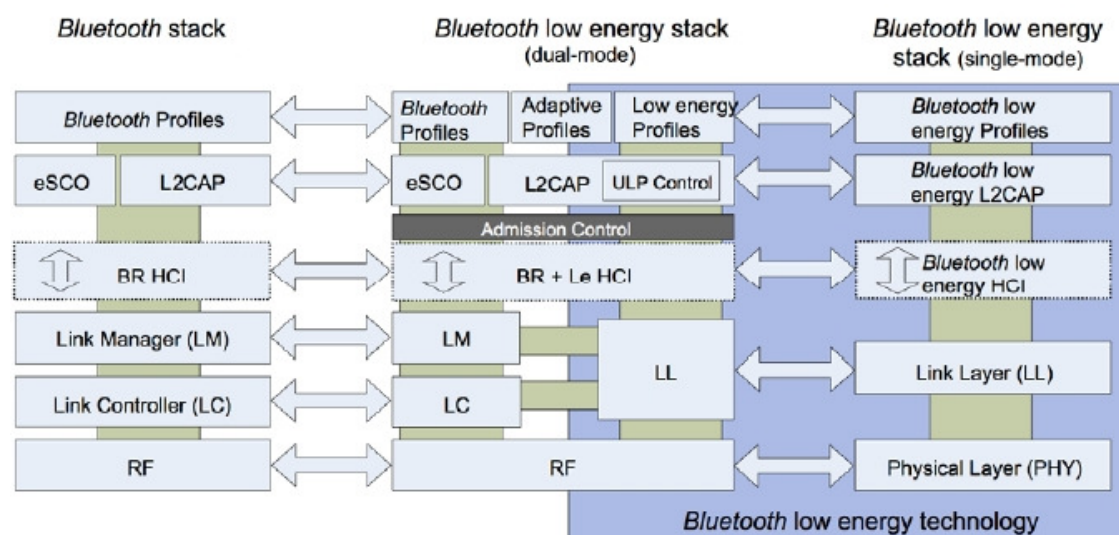

Figure36. Dual-mode and single-mode [URL59]

The modified Bluetooth low energy protocol has remarkable features mentioned in technical BTLE specification as a Link Layer (LL). As well the single mode has a

simplified design and next mentioned feature is point-to-multiple point data transmission with advanced power save and data encryption.

The LL provides scheduling for Bluetooth low energy wireless technology, traffic between devices in dual-mode and single-mode. [URL59]

4.4 Overview of LL states

There are five main operation states of the Link Layer can be characterized in terms of a state machine: Standby State, Advertising State, Scanning State, Initiating State and Connection State. The state machine allows only one of the current states at a time.

To move from one state to another states or commands from the link manager are used or internal signals in the link controller are used such as the trigger signal.

Device in the low power mode operates to get minimum power consumption through smart listening devices and responding packets on device requests. In the Advertising state device will be sending packets and possibly listening or responding on the packets.
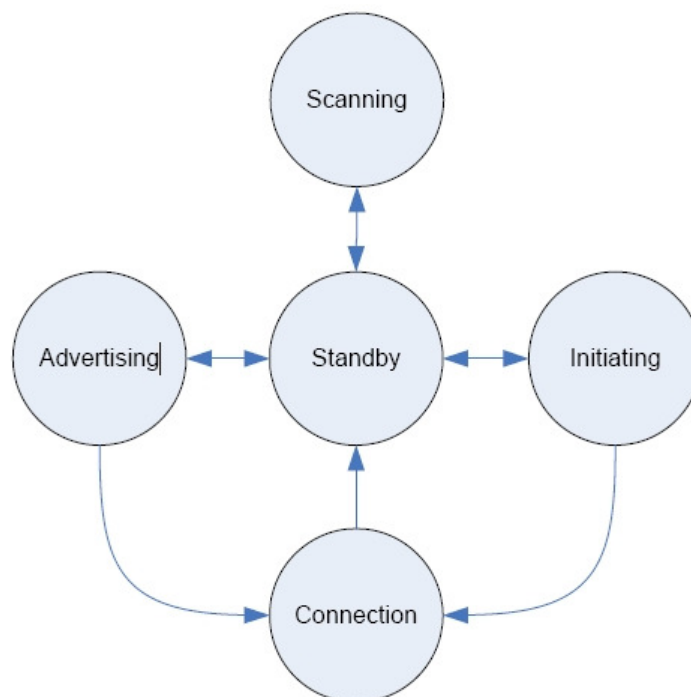

Figure37. State diagram of the Link Layer state machine [URL61]

In Scanning mode all devices are scanned in order to find an active one. The mode differs from Initiating state so that it listens the packages from specific device or devices and as a respond to initiate a connection with another device.

The Standby state is the default state in the device. During the state Link Layer doesn't transmit any data. In this state, the device may be in a low-power mode. The controller may leave the Standby state to scan for page or inquiry messages.

The Link Layer can support multiple state machines the following limitations have to be applied in Connection state during operation to Bluetooth devices. The link Layer in master mode may to have multiple connections and otherwise in slave mode has only one. LL doesn't operate with master and slave modes at the same time. Possible combinations of the states both allowable and prohibited are shown below. [URL61]

Multiple State Machine State and Roles		Advertising	Scanning	Initiating	Connection	
					Master Role	Slave Role
Advertising		Prohibited	Allowed	Allowed*	Allowed*	Allowed*
Scanning		Allowed	Prohibited	Allowed	Allowed	Allowed
Initiating		Allowed*	Allowed	Prohibited	Allowed	Prohibited
Connection	Master Role	Allowed*	Allowed	Allowed	Allowed	Prohibited
	Slave Role	Allowed*	Allowed	Prohibited	Prohibited	Prohibited

Table 3. Allowable and prohibited state combinations [URL61]

4.5 Network topology

Two different network topologies are organized for two Bluetooth modes. Single mode topology supports star topology, and according to dual mode implements star bus topology within PAN. The BTLE technology theoretically has no limit in number of active slaves in star and star-bus network topology. In single mode devices support star topology when one of the single mode devices acts as a hub that connects each

device by point-to-point link. As an example of the topology is an interaction between a remote control and TV-set acts as a hub. [URL60]
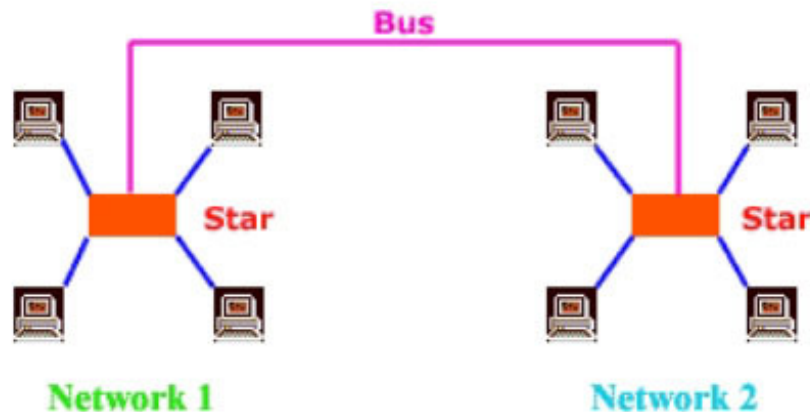

Figure38. Star and Bus Topologies [URL62]

Next Bluetooth topology is developed for different devices connecting at the time. It called as single and dual mode topology. Here, dual mode devices acts as the hubs and the single mode devices acts as nodes. Star bus topology is a combination of bus and star topologies. The topology is referred to point-to-multipoint link scheme. Several star topologies are connected by sharing common transmission link. On the bus only one hub can transmit data package at a time. A mobile phone supporting dual mode can simply establish connection to single mode sport pedometer, single mode watch and regular Bluetooth connection to a headset. [URL60]

4.7 Compared technical details

Comparing ZigBee and Bluetooth in common characteristics they look similar to each other. They are both from the same standard group IEEE 802.15 They use the same unlicensed 2.4 GHz operational frequency band to perform their low power connectivity and low cost. There are still some differences between two competitive technologies in their specifications. Bluetooth specification is based on IEEE 802.15.1 group and ZigBee implements IEEE 802.15.4. They are two different technologies in their design. At very beginning Zigbee more focused on controlling, monitoring and automation and Bluetooth belongs to be more focused on creating a network with laptops, mobile phones.

Bluetooth is designed to be used for self-organizing wireless ad-hoc networks. Ad-hoc networks do not have a permanent structure and provide decentralized wireless networks between devices. Devices are connected dynamically and forming a network. Each node in the network tries to transmit data destined to other nodes in dynamical mode. [URL68]

Zig Bee is focused on sending small amount of monitoring information and offering longer transmission between distances. It is the best solution for static networks where devices are not frequently used and suitable to transmit small data.

ZigBee looks almost like Bluetooth Classic but has a lower data rate and spends most of its time in sleeping mode. Recent Bluetooth Low Energy as well as ZigBee is able to run their batteries for years.

- **Over the air data rate**

ZigBee has lower data rate then Bluetooth.

ZigBee: 250kbps at 2.4GHz, 40kbps at 915MHz and 20kbps at 868MHz.

Bluetooth Classic is varied 1 to 3Mbps

Bluetooth LE: 1Mbps

- **Method of modulation**

ZigBee: Direct Sequence Spread Spectrum

Bluetooth Classic, Bluetooth LE: Frequency Hopping Spread Spectrum

- **Network topology**

ZigBee uses star, cluster and mesh

Bluetooth Classic: Scatternet

Bluetooth LE: Star-Bus

- **Number of nodes per network**

ZigBee allows up to 254 nodes per network.

Bluetooth allows up to 8 slave nodes in a basic master-slave piconet set-up.

Bluetooth LE: allows one-to-many connections. Billions of devices can be connected by using a star-bus topology.

- **Connecting time of a node**

ZigBee can wake up and get a packet in around 15 milliseconds.

For Bluetooth device, it would take 3 seconds to wake up and respond on request.

- **Output power level**

ZigBee: minimum 1.0 mW (0 dBm) and maximum 100 mW (+20 dBm)

Bluetooth LE: minimum 0.01mW (-20 dBm) and maximum 10mW (+10 dBm)

Here minimum power is a device in sleeping mode and maximum corresponds to the operating state of the device.

Technical Specification	Classic *Bluetooth* technology	*Bluetooth* low energy technology
Radio frequency	2.4 GHz	2.4 GHz
Distance/Range	10 meters	10 meters
Over the air data rate	1-3Mbps	1Mbps
Application throughput	0.7-2.1 Mbps	0.2 Mbps
Nodes/Active slaves	7- 16,777,184	Unlimited
Security	64b/128b and application layer user defined	128b AES and application layer user defined
Robustness	Adaptive fast frequency hopping, FEC, fast ACK	Adaptive fast frequency hopping
Latency (from a non connected state)		
Total time to send data (det.battery life)	100ms	<6ms
Government regulation	Worldwide	Worldwide
Certification body	Bluetooth SIG	Bluetooth SIG
Voice capable	Yes	No
Network topology	Scatternet	Star-bus
Power consumption	1 as the reference	0.01 to 0.5(depending on use case)
Peak current consumption	<30 mA	<15 mA (max 15 mA to run on coin cell battery)
Service discovery	Yes	Yes
Profile concept	Yes	Yes
Primary use cases	Mobile phones, gaming, headsets, stereo audio streaming, automotive, PCs, etc.	Mobile phones, gaming, PCs, watches, sports & fitness, healthcare, automotive, home electronics, automation, Industrial, etc.

Table 4. Specifications of Classic Bluetooth and Bluetooth LE [URL10]

5 CONCLUSION

In the conclusion the most important question comes up to make a final decision "What is the best technology, ZigBee or Bluetooth?" I would say there is no certain answer. In understanding of differences between them we have to look at and compare their specific technical features. Certainly ZigBee and Bluetooth technologies become closer to each other in low power characteristics. Especially last Bluetooth Low Energy approaches to the main goal to provide low power consumption in data transmission. They are obviously overlapping in some applications, for instance in Personal Health care of Home Environment areas in order to give a new possibilities for applications. They both have their own advantages and disadvantages. Bluetooth is capable to communicate within Personal Area Network to thousands and thousands of Bluetooth devices but can not work with mesh topology that allows flexible network topology in case when some node becomes not able for transmission. Bluetooth is based on star topology with a central device which simply can dynamically add devices into network or drop the device connection off. On other hand, ZigBee covers large Local Area Network but is not so much appropriate for ad-hoc wireless network.

Differences in synchronization of devices give a main solution how to save energy. Bluetooth LE has to wake up both master and slave synchronously, it gives keeping the same power consumption on low level. ZigBee power consumption is higher than Bluetooth, because it provides asynchronous mode that keeps only routers active all the time and end devices can be added at any time.

In a close future the Bluetooth LE will become the only standard for Bluetooth devices. Nowadays, Bluetooth Low Energy is definitely the most attractive technology. It offers an intermediate solution including single and dual modes. This is significant solution for people who already have previous versions devices and are going to use the new technical approach.

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