Bluetooth Low Energy – Assessment within a Competing Wireless World

Mohamed Habbal
Atlantik Elektronik, Fraunhoferstr. 11a, 82152 Planegg, Germany
Tel.: +49 (0) 89 / 89 505 154, Fax: +49 (0) 89 / 89 505 4154, Email: m.habbal@atxx.de

Abstract

Many innovative new use cases are now being made possible with the introduction of the new wireless technology named Bluetooth Low Energy (BLE). Being emerged and adopted by one of the largest wireless special interest groups, the Bluetooth SIG, the new technology aims to target the market in many fields, such as cell phones, health and fitness devices, home automation, heating, ventilating, and air conditioning (HVAC), remote controls, gaming, human interface devices (HID), smart meters, payment, and many others. These applications are all characterized by the following critical key requirements: ultra low power, low cost, physical size and ease of use.

Other low power wireless technologies have been available for decades for such coin-cell battery based applications, like ANT, ANT+, ZigBee, Nike+, NFC, RF4CE and IrDA. So, one would ask; why Bluetooth Low Energy? What reason could motivate for instance a health products supplier to switch from using an existing technology to Bluetooth Low Energy? What is the market vision and estimated expansion of this new technology?

This paper provides answers to these questions, together with a detailed analysis of the pros and cons of the various low power wireless technologies mentioned above. This includes radio specifications like power consumption, data throughput, covered distance, jamming resistance, coexistence, and topological support. Besides, the software stack and available profiles of Bluetooth Low Energy are also compared to BLE's nearest competitor in health and fitness market: ANT+. The goal of this paper is to introduce the new Bluetooth Low Energy wireless technology and compare it with other low power wireless technologies from all possible aspects, to help engineers and decision makers decide which technology is most suitable for their intended products.

1 Introduction

For over a decade, a demand for a new low power wireless standard started to grow worldwide for different industrial fields, such as home and building automation, health, sports and fitness, medical, sensor networking, and even the automotive field. The desired characteristics for such a wireless standard were quite simple: a standard that is capable of sending low amount of data payloads, but at the same time with a very low latency and ultra low power consumption. The standard should enable a CE device to work using a coin-cell battery that lasts for years. But where to find such a standard?

Many attempts were made in the past years, and several wireless standards emerged, while others were adapted, to achieve this goal. Many manufacturers and members of wireless standards SIGs claim that their wireless standard covers such demand. Among these wireless standards are ANT, ZigBee, Nike+, NFC, RF4CE, IrDA, low power proprietary standards and BLE.

ZigBee is one of the first low power standards that emerged (2002) to cover this demand for the home and building automation and sensor networking fields. Individual ZigBee devices must have a battery life of at least two years to pass ZigBee certification. ANT/ANT+ also emerged several years ago (2004) for the same purpose, but was somehow limited to health, fitness and medical field applications. BLE is one of the latest wireless standards that was finally released to achieve the same goal (although initially proposed by Nokia under the name Wibree in 2003 already), but for a much wider industrial field, including all the previously mentioned fields, in addition to automotive, and mobile CE smart devices like smartphones and tablets.

The goal of this paper is to introduce the new Bluetooth Low Energy wireless technology and compare it with other low power wireless technologies from all possible aspects, to help engineers and decision makers decide which technology is most suitable for their intended products. It should be noted that this paper does not describe each of the mentioned wireless standards in full details, but rather shows the main differences between them. Therefore it is assumed that the reader has some prior basic knowledge about these standards.

This paper is organized as follows: section 2 compares between all low power standards mentioned above regarding power consumption, throughput, range and latency. Section 3 compares between the standards which, as a conclusion of section 2, appear to be more appropriate for sensor networks and generalized low energy applications. Finally the paper is concluded in section 4.

2 General comparison and technical specifications

The main characteristics and technical specifications of the various previously mentioned wireless standards are presented and compared in this section.

2.1 Power Consumption

2.1.1 Average power consumption (for battery life time estimation)

It is quite a challenge to lay out numbers stating the average current consumption for each wireless low power standard, since it depends on many vendor specific parameters, some of them are SW related while others are HW related. Another issue is the many different operating modes and states of each standard. To demonstrate these challenges, an example is given to show how the average current consumption is estimated by one of the vendors of BLE chips. BLE has different operating states: advertising, scanning, standby, initiating and connection [2], as shown in figure 1. For each of these states, the current consumption varies again according to the sub-states. If we take the advertising state for example, the current consumption during transmission (I_Tx) differs from that during reception (I_Rx), as shown in figure 2. By SW related parameters we mean standard specific parameters that the user could adapt to suit his application, such as scan interval, advertising window, number of advertising channels used, etc. By HW related parameters we mean parameters related to the HW components either used inside or external to the chip. A formula provided by one of the BLE chip vendors that describes how the average current consumption is calculated during advertisement is shown below:

T= Advertising interval, (i.e. 0.5s)
D=Advertising data, (i.e. 20 bytes)
DC/DC converter enabled
$I\_av = ((C\_{adv\_DC} + (D * C\_{adv\_byte})) / T) + I\_{idle}$
$= (15\mu C + (20 * 0.4\mu C)) / 0.5s)\mu A + 2\mu A$
$= 46\mu A + 2\mu A$
$\mathbf{Iav} = 48\mu A$
Where C_{adv_DC} and C_{adv_byte} are the HW related parameters [2].

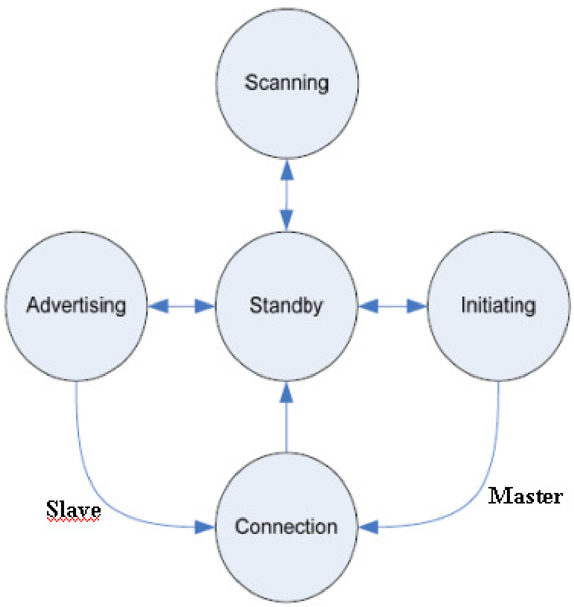

Figure 1: BLE operating states [2]

Even in the idle mode itself (i.e. neither transmitting nor receiving), BLE defines different low power modes, which are Deep Sleep, Hibernate and Dormant. Similar modes are found in traditional Bluetooth, such as sniff sub-rating, hold and park modes [2]. As a summary, the Bluetooth SIG claims that BLE has an average power consumption lower than ANT and ZigBee by a factor of 1.5x for the first and 2x for the latter.

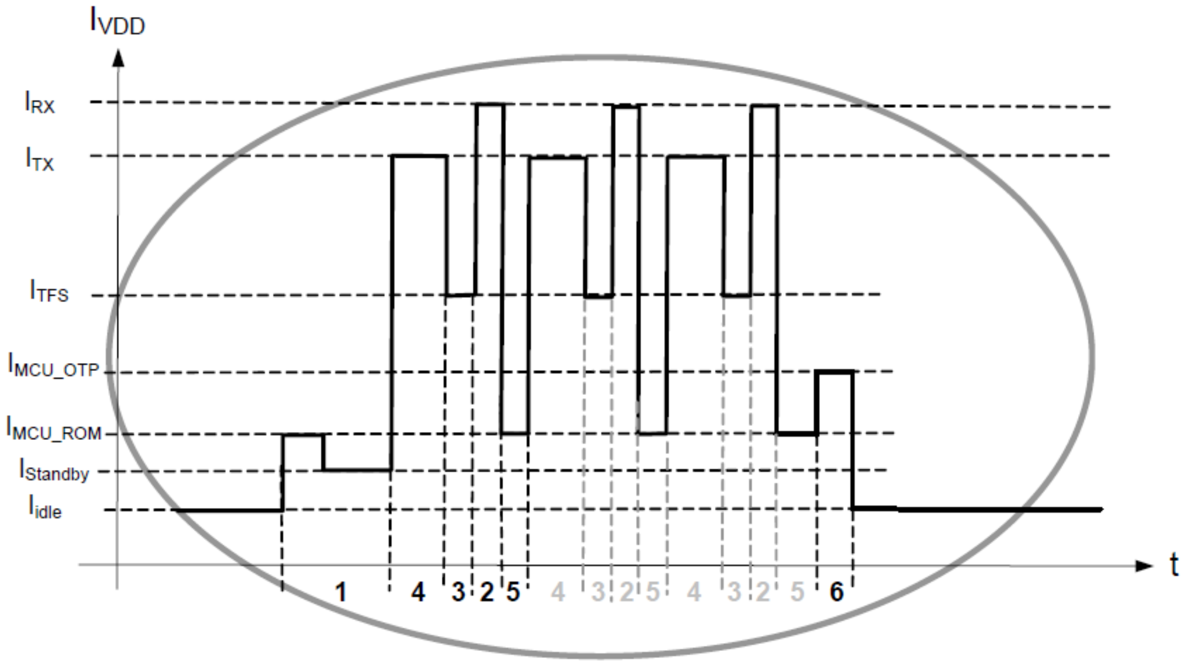

Figure 2: Example of average current consumption for a BLE chip during advertising [1]

2.1.2 Peak power consumption

Peak power consumption is a critical figure when designing long life low power sensor devices. The main reason for this is that certain types of battery technology are not able to source high currents instantaneously. The common CR2032 coin cell is a popular choice for long life sensor gadgets. However, it can only source about 15mA peaks without damage [20]. If the peak current exceeds 15mA then battery life may be degraded. Demanding 30mA peaks would reduce realized capacity by about 10% of manufacturers stated figures. Acceptable continuous standard loads are typically 2mA or less, in order to achieve published capacity figures.

Therefore, the various low power wireless standards are categorized above and below the 30mA threshold as shown below:

• IrDA peak current draw ~ 10mA [21]	
• Nike+ peak current draw ~ 12.3mA	CR2032
• BLE peak current draw ~ 12-16mA [22], [1]	OK
• ANT peak current draw ~ 17mA [7]	
• RF4CE/ZigBee peak current draw ~ 30-40mA [23]	Too
• NFC ~ 50mA [13]	high
• Wi-Fi peak current draw ~ 116mA (@1.8v)	current demand

2.2 Throughput

Throughput of a wireless network can be measured in two ways:

- On air signalling rate, which is often quoted on packaging (for example Wi-Fi 54Mbps). This is actually presenting the maximum throughput the radio transceiver is capable of. This in turn depends on physical layer related parameters such as channel bandwidth, modulation technique, number of bits per symbol, etc. Normally, this parameter is referred to as “max data rate” rather than “throughput”.
- The more useful method is to measure how quickly useful payload data can be transferred. This is often called “max actual throughput” as it measures the throughput above the second layer (data link layer) in the OSI model, which involves the time wasted in the logical bit encapsulation in packets, etc. The higher we go through the OSI model, the more time is wasted and the less throughput is achieved, due to additional tasks such as packet routing (3rd OSI layer, CRC checks and forward error correction, etc.). This is also due to the increasing size of headers in higher layers.

A good example that demonstrates the major difference between the first and second methods is the throughput values for ANT. The maximum “on the air” data rate for ANT is always stated to be 1Mbps, while the max actual throughput is only 20kbps, called “burst data rate” [5].

For the intended monitoring use cases, it is unlikely that ultra-high data rates will be needed regularly. The figures given below show how different technologies payload throughputs compare:

- IrDA ~ 1Gbps [14], typical values ~ 100-200kbps [21]
- Wi-Fi (lowest power 802.11b mode) ~ 6Mbps [15]
- NFC ~ 424kbps [10]
- BLE ~ 305kbps [16]
- ZigBee ~ 100 - 250kbps [17], [18]
- RF4CE (same as ZigBee)
- ANT+ ~ 20kbps [4], [5]
- Nike+ ~ 272bps

2.3 Range

The range of a wireless technology is often thought of as being proportional to the Radio Frequency (RF) sensitivity of a receiver and the power of a transmitter. This is true to some extent. However, there are many other factors that affect the real range of wireless devices. For example, the environment, frequency of carrier, design layout, mechanics and coding schemes. For sensor applications, range can be an important factor. Range is usually stated for an ideal environment (outdoors with Line of Sight), but devices are often used in a congested spectrum and in shielded environments. For example, Bluetooth is quoted as a 10 meter technology, but can struggle to provide a reliable Advanced Audio Distribution Profile (A2DP) stream from a pocket to headset, due to cross body shielding. Similar problems can be observed in the health and fitness space, where users have body mounted gadgets and move continuously. It is worth noting that 2.4GHz is easily attenuated by human bodies.
The following list shows typical ranges that can be expected from ultra low powered technologies in an open environment:

- NFC ~ 5cm [13]
- IrDA ~ 10cm-1m [14]
- Nike+ ~ 10m
- ANT(+) ~ 10m [12], [4]
- BLE ~ 50m [16]
- ZigBee ~ 100-300m [17], [18]
- RF4CE based on ZigBee ~ 100m
- Wi-Fi ~ 150-500 feet outdoors, in the 2.4GHz band [15]

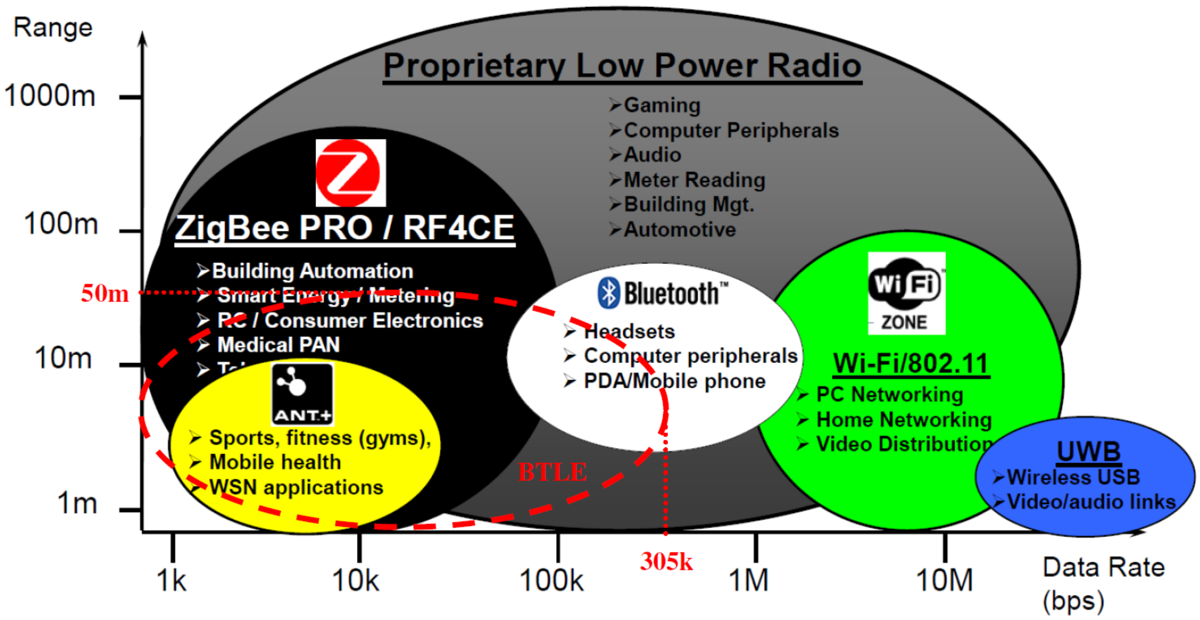

Figure 3: Comparison between BT, BLE, ANT and ZigBee regarding range and data rate [4]

2.4 Latency

The latency of a wireless system can be defined by a user action sent to a receiving device. A common scenario is gaming, where a user hits a button on the controller and the effect is perceived to be instant at the console. It is not acceptable that a user presses the trigger and must wait for a bullet to appear. Latency is also critical in applications such as HID (mice and keyboards), sports and fitness (instantaneous body readings) and security devices.

The list below describes some of the typical latencies of low powered wireless network technologies:

- ANT ~ “zero” with continuous scanning [19], [7]
- Wi-Fi ~ 1.5ms
- BLE ~ 2.5ms [16], [2]
- ZigBee ~ 20ms, wake-up time from Sleep: 30ms [17], [18]
- IrDA ~ 25ms [11]
- NFC ~ polled typically every second, this is manufacturer specific
- Nike+ ~ 1second

Although ANT and Wi-Fi have possible low latencies, they require the receiving device to listen continuously and therefore use considerable power. The previous references show that this low latency is often achieved only on devices that do not have strict power budgets.

2.5 Conclusion of section 2

After investigating and comparing between the characteristics and technical specifications of the various low power wireless standards, it is reasonable to group them into 2 categories: application specific and for general low power application. The first category would include IrDA, NFC, Nike+ and Wi-Fi. IrDA requires Line of Sight conditions, and also a target within less than 1m like in the case of NFC. Nike+ is a proprietary standard between Nike & Apple devices and supports very low data rates. Wi-Fi consumes too much power and could hardly be placed together with the low power standards. Maybe the new “low power Wi-Fi” standard would be more promising for such low power applications. The second category would include BLE, ANT/ANT+ and ZigBee since these 3 standards are considered suitable for sensor networks, while they possess many flexible parameters that can be adapted to suit many low power applications.

3 Why BLE

BLE, ANT/ANT+ and ZigBee are close competitors when considering general low power applications. Therefore, in this section, we shall try to go more in depth investigating more aspects beside the technical specifications presented in the previous section.

3.1 Bluetooth SIG and supported profiles

BLE market is expected to expand rapidly compared to that of ANT & ZigBee. This is because of the huge Bluetooth SIG that backs up the BLE standard. As a comparison between Bluetooth SIG and ANT SIG / Alliance, the number of members for the first is over 14,000 [3] compared to only 300 members for the latter by the end of 2010 [4]. For ZigBee, the SIG/Alliance size was around 358 members by December 2011 (13 Promoters, 128 Participants and 217 Adopters) [9]. This makes the Bluetooth SIG more experienced with a better market view and feedback for enhancements, and this in turn would speed up the emergence of new BLE profiles and services. Figure 4 illustrates the various ANT+ & BLE profiles (adopted and under development), while figure 5 presents those for ZigBee.

Figure 4: ANT and BLE profiles [4], [3]

Figure 5: ZigBee profiles [8]

3.2 Smartphones and Tablets

Bluetooth is integrated in most, if not all, smartphones and tablets, and was available in older mobile phones for more than a decade. Bluetooth and Bluetooth Low Energy (BLE) coexist in single chips now, called dual mode Bluetooth chips, also referred to as Bluetooth 4.0 dual mode chips. The strategy was to make it quite easy for smartphone and tablet manufacturers to replace the old

Bluetooth chip with the new dual mode chip. So, there is no need for dual antennas or additional peripherals. On contrary, some BT4.0 are made pin compatible with BT3.0 chips.
ANT is integrated only in 3 smartphones so far, while ZigBee can rarely be found in any smartphone or tablet-pc. For BLE, which was finally adopted in June 2010 by the Bluetooth SIG via the “Core version 4.0 specification”, the standard started to invade the market in many fields. The devices that support BLE only are called “smart devices”, while those that support both Bluetooth & BLE (integrating a dual mode chip) are called “smart ready devices” [3]. For “smart devices”, two vendors integrated BLE in their heart rate straps, while others integrated BLE in smart watches. For “smart ready devices”, BLE is integrated now in smartphones, tablets, laptops and PCs. With Apple joining the Bluetooth SIG two years ago, the Bluetooth & BLE market obtained a great push forward. For smartphones, BLE is found now in iPhone4S (iOS based) and Motorola Droid Razr (Android based). For Notebooks / Laptops, BLE is now found in MacBook Air and Acer Aspire A3. For PCs, Apple integrated BLE in the newest Mac-Mini. According to the Bluetooth SIG, BLE shall be fully supported on the iOS, Android and Windows phone 8, which represent more than 85% of the OS market for mobile devices. Bluetooth SIG also announced that it shall be hard to find a smartphone or tablet-pc that does not integrate BLE by the end of 2013.

Figure 6: Examples of smartphones integrating BLE; Motorola Droid Razr “Android based” (left) and iPhone4S “iOS based” (right)

3.3 Network Topology

Network topology describes how the nodes (or network devices) are connected to each other within a network, such as the bus and ring topologies. For wireless MANETs (Mobile Adhoc Networks), the most famous among these are the star and mesh topologies. The support of the mesh topology is preferred in many applications, since it gives the user the flexibility to connect any node with any other node within the network when desired. This is mostly needed in MANETs for fall-back situations in case of node failures, where the network should re-adapt (either autonomously or manually) its topology to remove the broken links and replace these with new links, in other words, re-adjust its routing table.
Generally speaking, network topologies are essential in two cases. The first case is if the wireless standard used consumes much time for a connection establishment, like Bluetooth v2.1 for example which takes about 2 to 6 seconds to create a connection, with 3 seconds as a typical average value. Hence it makes no reason to waste several seconds to just send a few bytes of data. Therefore, it is more reasonable to establish and maintain active connections to get rid of this delay. But since active connections consume much power, several methods are used to control the radio on / off time, as implemented in Sniff sub-rating in Bluetooth. The second case is if there are restrictions for the max response time (i.e. time between event-triggered action on the transmitting side and message reception on the receiving side), such as in gaming applications. Again, active connections are preferred for this type of applications.
ANT and ZigBee support mesh networking, while BLE, unlike Bluetooth, does not. This is because a slave node in BLE cannot connect to multiple Masters at the same time, i.e. can only connect to 1 Master for an ongoing active connection, but can still perform advertisement while connected [2]. This prohibits the formation of scatternets and mesh topologies, and only the star topology is supported. But by taking a look at the 2 cases discussed above, it is worth mentioning that this topology limitation is not a concern. For the first case, no BLE active connections are needed, since the overall message exchange time Tm (total time of create connection + send 1 packet + receive ACK + disconnect) takes only 20-30ms. This value is claimed by CSR and measured in our Lab using CSR BLE single mode

chips, with 1 data packet transmission with max 20 bytes data payload (excluding headers) over the GATT layer. If the communication takes place over HCI, this time is reduced to about 8 – 10ms. If several data packets need to be transmitted, the delay is extremely small as the T_IFS (Time of Inter Frame Spacing) is only 0.15ms [2], with typical latency of about 2.5ms as stated in Latency section 2.4. For the second use case like gaming applications, the communication is normally P2P or P2MP in most cases, hence a star topology is sufficient. As a conclusion, BLE is still appropriate for usage for most low power applications.

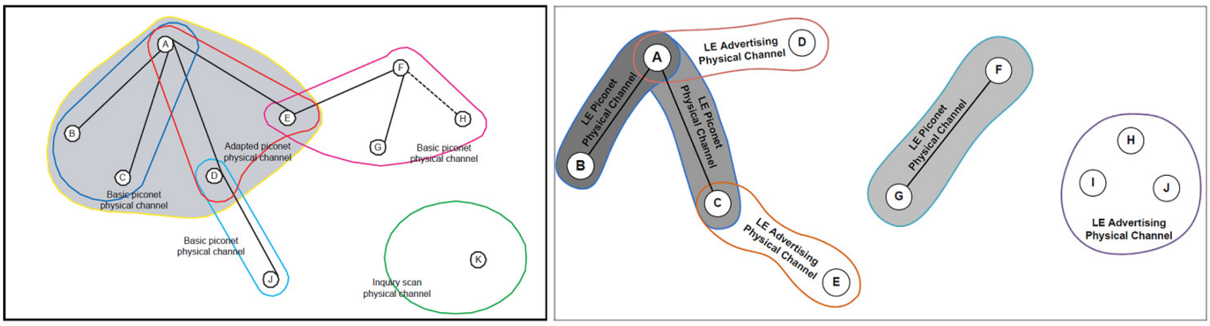

Figure 7: Comparison between BT (left) and BLE (right) network topologies [2]

3.4 Coexistence with Bluetooth

As all three wireless standards (BLE, ANT and ZigBee) operate in the 2.4GHz ISM band, coexistence and interference become important issues that need to be handled carefully. If a device is using several wireless standards that work in the same frequency band, the best way to avoid interference between them is to have a common MAC layer that switches between these standards in an appropriate manner. This common MAC layer performs channel quality measurements (like RSSI, Quality of Service and Packet loss rate for Bluetooth) in order to update the channel map with the "good" channels and remove those channels marked as "bad", etc. The common MAC layer should also perform time slot scheduling (if the standard in TDMA based like Bluetooth) for best management. Bluetooth 4.0 dual mode chips provide this common MAC layer for the best coexistence. This coexistence is very important since Bluetooth is one of the most widely used wireless standards, more than ANT and ZigBee. Currently, there are no common MACs that manage ZigBee with Bluetooth, while only one chip is announced to support both ANT+ and Bluetooth, which is the TI CC2567 chip [6].

3.5 Coexistence and interference immunity

This can be summarized in a very few words. BLE and ZigBee provide a better coexistence with other wireless standards in their vicinity than ANT since BLE uses Frequency hopping (FHSS) while ZigBee uses Direct Sequence (DSSS). ANT does not support any of these two techniques, but it uses TDMA with very small time slots (150us) and monitors channel interference, which is called adaptive isochronous network technology. This can be helpful when organizing time slots within an ANT network, but is useless regarding coexistence with other wireless standards nearby. The only technique ANT has regarding this matter is using frequency agility to hop to another channel (frequency carrier) which can then be subdivided into timeslots [5].

4 Conclusion and Discussion

Several low power wireless standards had emerged in the past years to cover the demand for a wireless standard that is capable of sending low amount of data payloads, but at the same time with a very low latency and ultra low power consumption. The standard should enable a CE device to work using a coin-cell battery that lasts for years. Among these wireless standards are ANT, ZigBee, Nike+, NFC, RF4CE, IrDA, low power proprietary standards, and BLE. After comparing between these standards regarding their technical characteristics, 3 wireless standards were found to be the most appropriate for general low power wireless applications, which are BLE, ANT and ZigBee. These 3 wireless standards were further inspected, and one could summarize the results as follows. BLE provides better technical performance than ANT regarding coverage, data throughput and immunity to interference, besides covering more field applications than ANT and the integration into mobile devices, but its major weakness is not supporting the mesh topology. The power consumption of ANT and BLE is almost the same. BLE is better than ZigBee from the technical point of view regarding power consumption, latency and wake-up time, but again ZigBee supports mesh networks while BLE does not. A major advantage of BLE is the BT SIG with its 14,000 members to drive this standard. As a result, BLE will shortly be available in almost all smartphone and tablet products. Comparing ZigBee and ANT together, it is hard to say which is better for an overall performance. ANT is better regarding power consumption, latency and simplicity of stack, while ZigBee is better regarding data rate and covered distance. It is up to the user to choose which wireless standard suits his application best by defining which parameters are of higher priority.

Abbreviations

BLE	Bluetooth Low Energy	ISM	Industrial, Scientific and Medical
BT	Bluetooth	MAC	Media Access Control
CSR	Cambridge Silicon Radio	MANET	Mobile Ad-hoc NETwork
DSSS	Direct Sequence Spread Spectrum	NFC	Near Field Communication
FHSS	Frequency Hopping Spread Spectrum	P2MP	Point to Multi-Point
GATT	Generic ATTribute protocol	P2P	Point to Point
HCI	Host Controller Interface	RF4CE	Radio Frequency for Consumer Electronics
HID	Human Interface Device	SIG	Special Interest Group
IrDA	Infrared Data Association	TDMA	Time Division Multiple Access

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