# Coexistence and Interference Tests on a Bluetooth Low Energy Front-End.

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***Abstract*—Over the last decade, impelled by the industry demand to achieve a technology capable of sending low amount of data payloads, but at the same time with a very low latency and ultra-low power consumption, several efforts in wireless network transmission standardization emerged, supporting new applications in health, sports and fitness, medical, sensor networking, and even the automotive industry field.**

**Despite the competition from ANT+, ZigBee, Nike+, NFC and RF4CE, in 2010 the Bluetooth SIG (special interest groups) adopted a new wireless technology named Bluetooth Low Energy (BLE). BLE coexist with Bluetooth in the same chip (called dual mode) therefore assuring this technology a rapid growth among smartphones, iOS, tablets, laptops and PCs. In fact, Bluetooth SIG also announced that it shall be hard to find a smartphone or tablet-PC that does not integrate BLE in the near future. Despite this accelerated growth, BLE shares the same band with Wi-Fi and all other low power technologies, so in order to achieve QoS, a mandatory requirement in many systems, tests for interference and coexistence must be performed. This study analysis the impact of a BLE sensor network on a crowded 2.4GHz room, with multiple Wi-Fi routers, ZigBee sensors and Bluetooth technology.**

**We also compare the results with the ones obtained inside an anechoic chamber on similar experiences.**

***Keywords—Interference Radiation; Sensor; Diabetes; Bluetooth Low-Energy (BLE)***

## I. Introduction

The International Diabetes Federation estimates that in 2013 more than 382 million people suffer from diabetes, this is a huge and growing problem, and the costs to society are high and escalating. The latest research shows that one in ten of the world's population will have diabetes by 2035, surging to a total of 592 million [1]. Diabetes Mellitus has become the most common chronic diseases in nearly all countries, and continues to increase in numbers and significance, as economic development and urbanization lead to changing lifestyles characterized by reduced physical activity, and increased obesity. Recent advances in wireless sensor networking technology have led to the development of low cost, low power, multifunctional sensor nodes that enable environment sensing together with data processing [2]. Instrumented with a variety of sensors, such as temperature, humidity, volatile compound detection, bio implanted sensors, the development of such networks requires testing for transmission distance and human body (HB) interference. These devices operate in the free 2.4 GHz ISM band, the same band that Wi-Fi signals operate, therefore several tests regarding interference, robustness and coexistence were made to ensure Quality of Service (QoS) in order to achieve medical diagnostic equipment status. Glucose subcutaneous BLE sensor, can help patients to constantly monitor their glucose levels and issue alarms to a cellular phone or wrist watch [3]. This factor can contribute to the close collaboration between those affected and their healthcare providers in order to prevent a range of costly, dangerous complications, on humans' eyes, kidneys, feet and heart, or even early death in 13% of these patients when left untreated.

Smart ready devices, are devices that support both Bluetooth & BLE (integrating a dual mode chip) like smartphones, tablets, laptops and PCs, while smart devices are often use to refer the devices that support only BLE like BLE sensors. Several vendors integrated BLE in their heart rate straps, while others integrated BLE in smart watches. 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.

The coexistence between Bluetooth & BLE on the same device is assured by the common MAC layer. This layer also 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" [4].

There are 79, 1 MHz bandwidth, channels available for Bluetooth while BLE uses only 40, 2 MHz bandwidth, channels, but booth channels are narrow band signals. ZigBee is also a narrow band signal with a 3 MHz bandwidth but only uses 16 channels spaced by 5MHz. Unlike Bluetooth or BLE it uses Carrier Sense Multiple Access with Collision Avoidance (CSMA CA) in order to avoid interference by sensing the in-channel power before transmitting if the measured power is below a given threshold, meaning that the medium is actually not busy, and then the transmission can begin. Otherwise, after a random back off period, another attempt is performed. This technique is use, also, by WI-FI routers in their transmission scheme. The crowded spectrum can be seen on fig. 1.

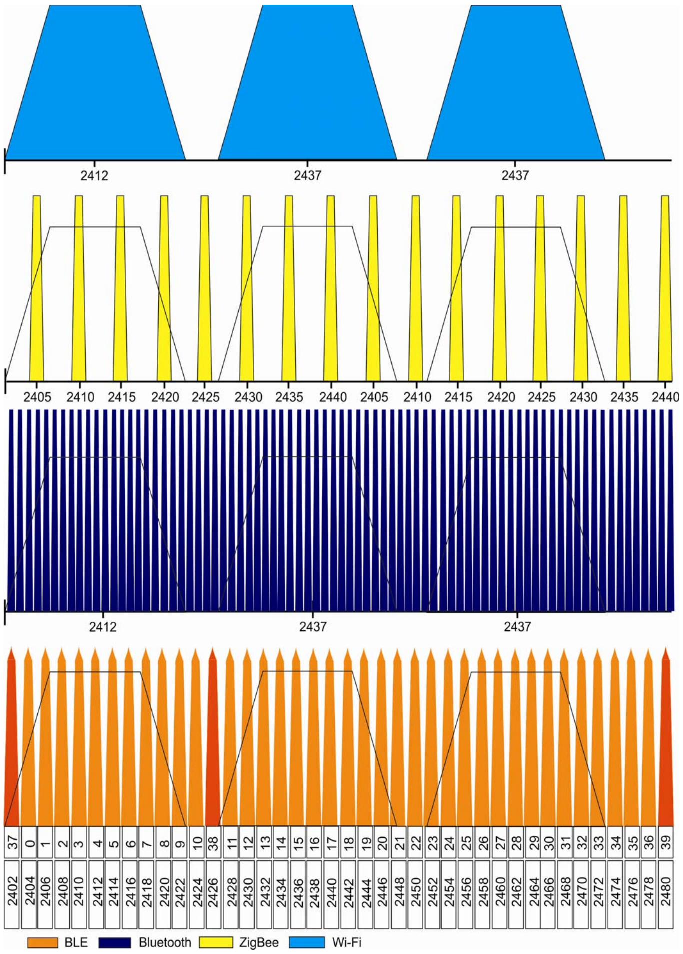


Fig. 1. Wi-Fi, ZigBee, Bluetooth abd BLE spectrum.

ZigBee allows dynamic channel selection, a scan function steps through a list of supported channels in search of beacon, receiver energy detection, link quality indication. A feature called frequency agility is specified in the ZigBee standard to improve the robustness of ZigBee networks, according to this function, if interference is detected and reported in the current channel, a ZigBee network may move to a clear channel based on some mechanisms. ZigBee's operation in 2.4GHz band is aided by the choice of 16 available channels. The frequency agility function makes using these extra channels easier. When a network is first formed the node seeks a channel with the least noise or traffic. If overtime extra traffic appears or noise becomes present, the host application scans for a better channel and moves the whole network to the new channel allowing the network to adapt overtime to changing RF environments. In the case of Fig.1 there are 4 available channels for the Zig-Bee network to operate without Wi-Fi interference. If we add to the same space a Bluetooth network, some collisions between Zig-Bee and Bluetooth are expected to append, nevertheless ZigBee is a DSSS system, not a kind of frequency hopping system, so there is only one time channel overlap in 20 times ( in case of high occupied band Bluetooth will reduced the number of transmission channels to 20). Also Bluetooth transmission takes around 366 μsec so the collision is further reduced by this factor. On other hand Wi-Fi signals will see Bluetooth as narrow band interference and only in the cases that the Bluetooth interference is not more than 10 dB below the Wi-Fi signal can occasionally cause interference. In most cases Wi-Fi transmits 20 dBm and Bluetooth transmits 0 dBm so if we take into account the path loss Friis equation of the transmitted Wi-Fi signal

$$L_{path} = -27.55 \text{ dB} + 20 \log(2.4\text{MHz}) + 20 \times \log[\text{dist(m)}]$$

and the Link Budget equation

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB) − $L_{path}$

We get to the theoretically conclusion that only if the Wi-Fi Router is more than 3 meters away from the connecting equipment and the Bluetooth equipment is on a 3 meters area around the Wi-Fi equipment, that occasionally the Bluetooth signal can cause interference over the Wi-Fi.

Wireless Body Area Networks (WBAN) is the term that is used for wireless sensor and control networks worn or implanted on HB. These sensor nodes are used to monitor vital signs such as body temperature, heart rate, SpO2, blood glucose or electrocardiogram [5]. The IEEE 802.15.6 standard was released on February 2012 [6] and consists of a single Medium-Access-Controller (MAC) which supports a star or two hop star network topology with QoS support, Medical Implant Communication Service (MICS) band communication for body implanted devices and emergency communications. In addition to the MAC, there are three possible physical (PHY) layers: the Narrow Band (NB); the UltraWideBand (UWB); and the Human Body Communications (HBC)[7]. Since only the NB PHY is architected specifically for biotelemetry applications and uses the Industrial-Scientific-Medical (ISM) free band, the same band that BLE uses, this is the only part of the standard that will be compared.

The Bluetooth Special Interest Group adopted BLE towards the backend of 2010 for low data rate (small packets) and infrequent communication from nodes, where the critical low power requirement is needed, to a hub in a mobile phone or web service. If we compare the two standards on the PHY level we can see that BLE meets many of the IEEE 802.15.6 standard specifications and takes advantage of the Gaussian Frequency-Shift Keying (GFSK) modulation, compared to the IEEE 802.15.6 requirement for rotated differential phase-shift keying (DPSK) to lower power consumption for episodic data transmissions [8]. One other major advantage from the BLE is that it has significant market penetration due to the fact that most new mobile platforms and Windows 8 are expected to have Bluetooth Version 4.0 features and hence LE functionality. According to published forecasts, BLE is expected to be used in billions of devices in the near future [9]. The use of BLE in WBAN and Personal Area Network (PAN) can help the development of Ambient Assisted Living systems as the one developed by Hugo *et al.* [10]. The developed system collects data from a wireless sensor that transmits data over BLE to a PC application developed in Java supported by a

USB dongle [11]. Although several studies cover the interference between Bluetooth and Wi-Fi [3][12][13] and ZigBee with Bluetooth and Wi-Fi[18], we didn't find any studies on the interference between BLE and other coexisting technologies like Wi-Fi, Bluetooth and Zig-Bee that work on the same free 2.4 GHz ISM band.

## II. MATERIALS AND METHODS

All measurements were perform in a full anechoic chamber with walls, ceiling and floor cover with high loss microwave absorbers (ECCOSORB VHP-12-NRL). A PC USB dongle acts as receiver for the Java developed application [4], were several AAL sensors, like temperature and humidity as well as the Receive Signal Strength Indicator (RSSI) average data, packet count and errors for the four locations were recorded. Fig. 2 presents the test measurement setup. Three devices were tested, two SensorTag from Texas Instruments (TI) [14], and the BLED 112 from Bluegiga [15].

The locations were designated has 1, 2, 3 and 4 where the distance between the Sensor and the receiving station was respectively 1, 2, 3 and 4 meters.

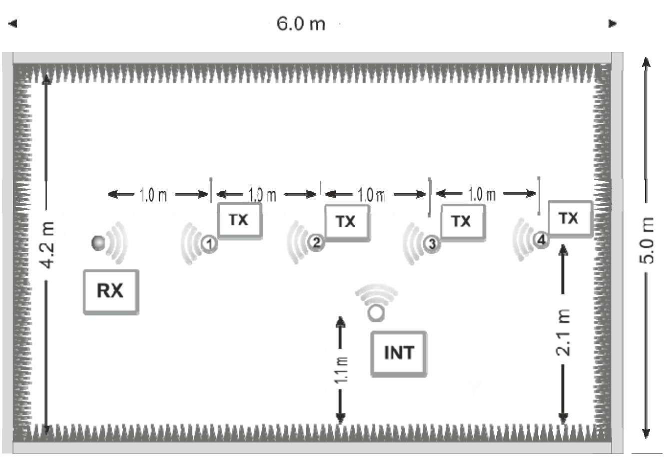


Fig. 2. The test measurement setup

For the interference there were two types configured: the first one uses the HP ESG-3000A signal generator with a SkyCross 22-1328 antenna and an FM modulated signal center on 2.44 GHz, 80 MHz bandwith with 10 dBm power; the second uses three Wi-Fi routers on bands 1, 6, and 9. Both interferences were configure at 2.7 m from the receiving station.

The receiver, BLED112 dongle, was programmed to transmit 0 dBm (to do that on the `<txpower>` tag we must use a value of 15 thus enabling 0 dBm to be transmitted), on the transmitter side the SensorTag, the TXpower setting was `0xE1` to enable up to 0 dBm to be transmitted. The receive sensitivity for both was −93 dBm.

For all the experiments two nodes were configured as a designated transmitter or receiver. The receiver is positioned in a fixed location and the transmitter is suspended in free space (OS) as can be seen in Fig. 3. The position number indicates the distance between the receiver and the transmitter, both are suspended at 0.90 m above ground and the interference is 2.7 m from the receiver and 0.60 m above the ground.

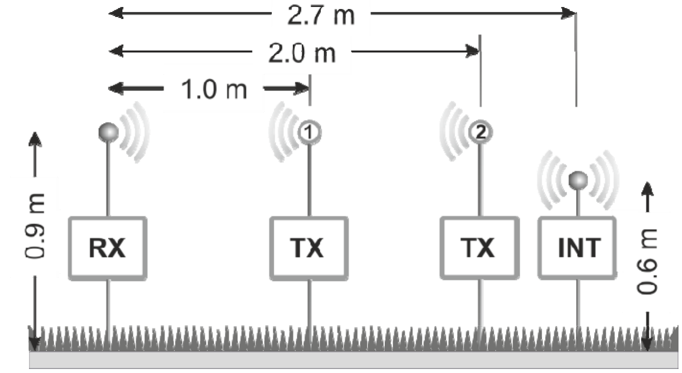


Fig. 3. Side view setup for position 2 measurements

The anechoic chamber setup for position 4 is shown in Fig. 4, the SensorTag is on top of the tripod and the Laptop holds the dongle with the receiver station and Java application.

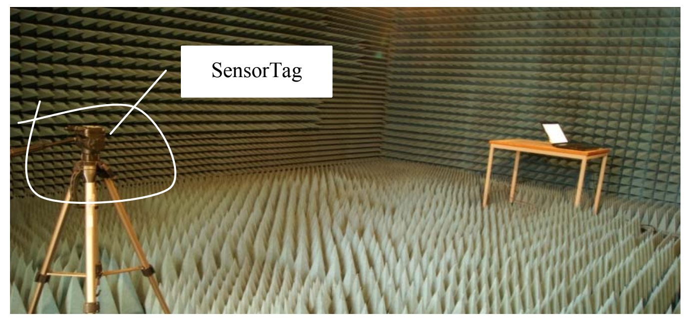


Fig. 4. PC and SensorTag inside the anechoic chamber

All signals were measured with the Advantest U3641 spectrum analyzer with a SkyCross 2-2931-A antenna as can be seen in Fig. 5.

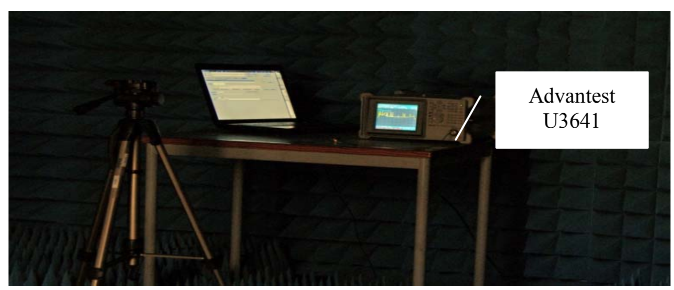


Fig. 5. Spectrum Analyzer Advantest U3641

To test the effects of the implanted HB the SensorTag was covered with pig skin as can be seen in Fig. 6, in order to simulate the wave absorption by the patient's skin.

For the Wi-Fi interference tests three Wi-Fi signals were mounted, in order to completely block the free transmitting band: one in channel 1, another in channel 6 and the last in channel 9 all with signals measured −53 dBm from the PC side.

## III. RSSI READOUT VS INPUT POWER

The RSSI is a numeric value from 0 to −255 that measures RF energy defined by the IEEE 802.11 standard [16] in order to evaluate, for example, if a certain channel is clear for transmitting. However different company's use different values to measure the signal strength: TI for example uses values between −40 to −103 for measuring the input power in a linear way, each means that, if the read value is −68 it means the RF power is −68 dBm. The drawback is that values above −40 for example 0 dBm or −10 dBm are reported both as −40 dBm. Nevertheless for transmission purposes, the reading values from −40 to −103 dBm are enough, especially because less than −93 dBm it's impossible to distinguish between noise and signal. By other hand RSSI readings vary a lot, so the average for 246 readings was taken in to account for every test setup.

Fig. 6. SensorTag before being cover with Pig Skin

## IV. Results

### A. Experiment Overviews

The distance between the transmitter and receiver is controlled and increased from 1.00 m to 4.00 m with increments of 1.00 m. At each location, the transmitter node transmits, during four minutes, 246 packets and the received data is logged by the host PC Java application [4]. The PC application stores the RSSI average data, packet count and errors for each location. On a second set of tests three Wi-Fi signals were configured to transmit full power on channel 1, 6 and 9 respectively. On the third set tests were made using the SensorTag cover with tissue in order to determine body interference and radiation absorption.

### B. Human body interference

The results on Table I resume the average readings for 246 packets transmitted, in case of HB and Open Space (OS). The HB interference show that the RSSI readout values suffer a drop between 6 to 10 dBm when compared to OS. They also show that this drop associated to the initial collisions, of the full spectrum interference (INT), results in a connection drop by the sensor and didn't allow the sensor reconnection. Results also show that the system adapts to the interference as the average number of TxRetry reduces when compared to the no interference situation.

TABLE I. RSSI and Transmitted Packet

| Transmitted Packet number | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dist | Type | INT. | ***RSSI*** | ***TxOk*** | ***RxOk*** | ***TxRetry*** | ***RxFail*** |
| 1 m | OS | OFF | -70 | 246 | 153 | 93 | 0 |
| | | ON | -68 | 246 | 205 | 40 | 0 |
| | HB | OFF | -66 | 246 | 48 | 198 | 0 |
| | | ON | -65 | 246 | 100 | 146 | 0 |
| 2 m | OS | OFF | -76 | 246 | 96 | 150 | 0 |
| | | ON | -71 | 246 | 205 | 41 | 0 |
| | HB | OFF | -80 | 246 | 202 | 44 | 0 |
| | | ON | -78 | 246 | 212 | 34 | 0 |
| 3 m | OS | OFF | -80 | 246 | 198 | 45 | 0 |
| | | ON | -79 | 246 | 199 | 47 | 0 |
| | HB | OFF | -85 | 246 | 204 | 42 | 2 |
| | | ON | ---- | ---- | ---- | ---- | ---- |
| 4 m | OS | OFF | -79 | 246 | 194 | 60 | 0 |
| | | ON | -83 | 246 | 214 | 32 | 0 |
| | HB | OFF | -82 | 246 | 200 | 46 | 1 |
| | | ON | ---- | ---- | ---- | ---- | ----- |

### C. Coexistence with Wi-Fi

Due to their dependence on the same band, the potential for interference exists. Therefore it is important to see if there is interference from Wi-Fi on the BLE transmissions. The results show no effect on the Bit Error Rate or RSSI readout, in fact the RSSI readout shows that the value increases. The results obtained show that BLE hopping is effectively avoiding the Wi-Fi occupy channels, therefore there is very good coexistence between BLE and Wi-Fi.

### D. Coexistence with Bluetooht and X-Bee

X-Bee and Bluetooth share the same free band as BLE, and although Bluetooth technology share a similar hopping scheme for avoiding occupied bands as BLE, there is still a potential for collisions and interference between this technologies. A Bluetooth pen was use to see how the BLE reacts to it and Table II summarizes the results for the RSSI and transmitted Packet average for Bluetooth (B) and X-Bee (X) with or without Full Band Interference. It's clear that the Bluetooth did collide a few times more with BLE than X-Bee because we see an increase in RSSI power and on the TxRetry needed for the system complete the 246 transmitted packet Ok.

TABLE II. RSSI and Transmitted Packet / Bluetooth and X-Bee

| Transmitted Packet number | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dist | Type | INT. | ***RSSI*** | ***TxOk*** | ***RxOk*** | ***TxRetry*** | ***RxFail*** |
| 1 m | B | OFF | -64 | 246 | 145 | 101 | 0 |
| | | ON | -64 | 246 | 146 | 100 | 0 |
| 1 m | X | OFF | -74 | 246 | 153 | 96 | 0 |
| | | ON | -74 | 246 | 156 | 90 | 0 |

## V. Conclusion

BLE is an exciting new technology that enables new frontiers, thanks to the adoption from the major cellular phone companies, but although it's with spreading more work must be done by developers in order to ensure QoS to both patients and doctors. The results show that HB absorbs part of the emitted signal thus reducing the distance for the receiving station in case of implanted sensors. The good coexistence between BLE and other technologies that use the same spectrum like Wi-Fi signals, Bluetooth, X-Bee was also proved although further studies concerning Wi-Fi throughput in the presence of BLE should be persecuted.

## VI. Future Work

Finally, although, our experiments did not intend to infer the location from the received RSSI values future works may explore this area since inferring location from RSSI as became increasingly subject of much research in recent years [17] and a high set of data has been logged. Anechoic chamber radiation patterns of both PC dongle and SensorTag should be persecuted in future works to better estimate the propagation and direction of the BLE waves.

## Acknowledgment

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