ENERGY MODELING AND POWER CONSUMPTION IN BLUETOOTH LOW ENERGY STANDARDS: AN EXPERIMENT & COMPARATIVE MEASUREMENTS WITH TRADITIONAL BLUETOOTH FOR IOT APPLICATION

[1]Rahul Shrimali , [2]Hemal Shah, [3]Jaydeep Gajera

[1] Asst. Professor & Head, [2]Dean, ICT, [3] PG Scholar Department of Computer Engineering

[1] Department of Information Technology

[1] Aditya Silver Oak Institute of Technology, Silver Oak Group of Institutes

Abstract: The Internet of things is making its way into every walk of our lives. IoT is omnipresent. The developments have paced in the past few years. The rapid increase in the usage of IoT in all domains does have its own share of risks. The large consumption of power that is possible in IoT's smart devices as they are constantly accessed by other devices is a major concern. The increased consumption of power is one of the neglected aspects of the smart devices of the IoT applications. It actually says that the unit of electrical energy that is consumed is not put to use effectively. The ultra-power communication mechanism is one of the important aspects when it comes to the deployment of IoT products in the market. For these reasons, the Bluetooth low energy is found to be very promising in nature. The energy that is in took by the Bluetooth Low energy is measured by the usage of a power monitor and the other derived versions of the energy behavior that is fundamental in nature observed from that of the measured outcomes. In our work, the overhead of IPv6 based communication over BLE is explored. This can be put to use for the future IoT scenarios and the results can be contrasted by doing similar kind of experiments. Here, the results show of how the BLE is very energy efficient in terms of the number of bytes transferred per Joule spent. We also developed and tested our modeling on the Android interface to get the results by the receival of the signals that are taken from the Received Signal Strength Indicator (RSSI). These values are measured in dBm which is later converted into Joules for the calculation of energy.

Index Terms **- Bluetooth, Microchip RN4020, BLE, IoT, iBeacon, RSSI**

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I. INTRODUCTION

In today's era, Bluetooth Low Energy (BLE) devices found more suitable for Near Field Communication as increasing number of sSmartphone users and mobile devices. BLE is attracting researcher community due to lightweight, more energy saving solution from modern version of the same family. In June 2010, BLE was developed and launched with the aim to offer core specifications with 4.0 version. It is slowly and steadily becoming an emerging low-power wireless technologies best suitable for short-range monitoring and control applications that is expected to be integrated into billions of devices and will be so in popular amongst hardware designers within the next few decades [1]. For new variants of middleware and IoT application there was a huge demand of power saver design and version of the Bluetooth which attracts community with its cost and energy requirements. Crucially, BLE isn't companionable with conventional Bluetooth. In addition to that it differs with specifications [2].

Let's understand Protocol Stack in BLE shown in Figure -1, being a lower layers, data transmission is taken care by PHY and LL layers of BLE stack. LL layer also offers channel access, connection management, and error and flow control. It straightforward us e FHSS for accessing common channel available adaptively. However, hop count and width is not same as conventional Bluetooth standard (i.e. hop count = 43, Channel Width = 2 MHz). Data multiplexing, Fragmentation and reassembly job for higher size of packets is done by Logical Link Control and Adaptation Protocol (L2CAP). Host supported functionalities is offered by Generic Attribute protocol (GATT) & Generic Access Profile (GAP) respectively to realize application layer [2][3].

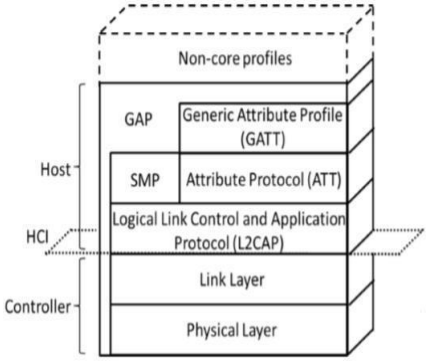


Figure: 1 Protocol Stack in BLE [1]

Bluetooth connectivity available in both the modes (Master & Slave) provides an opportunity where a master can handle several concurrent communications is possible by connecting slave devices. The only constraints with slave is it does not have more than one master. And hence star topology is realized in such kind of connections. As compare to classical BT, discovery of nearby devices can get done through slave advertisement through one of three selected advertisement channels [2]. For slave detection, Master need to start scan. Once scanning & discovery of such nearby slaves get over, Master and slave wakeup and transmits the data frame to establish fresh connection ans start exchange subsequent frames. Except this duration, both devices always choose to remain in sleep state. It's a technology that has attracted us because of one thought-provoking claims done by developers of iBeacons[5], preliminary stimulus has stemmed in a different principles of efforts. Table 1 shows the comparisons between different communication technologies in trend. We can easily conclude from this summary that why BLE is more focused and should be attended by research community.

Technology	NFC	RFID	BT	BLE	Wi-Fi	Zigbee	WPAN	WiMax	2G-3G
Power	Low	Low	Low	Low	High	Low	Low	High	High
Speed (Kbps)	400	400	700	1000	100000	250	250	100000	5000
Distance covered in Meters	0.01	3 0	30	50-70	15	300	800	50000	Depend Cellular n/w

Table 1: Communication Technologies [11] [12] [13] [14] [15][16][17][18]

II. BACKGROUND AND RELATED WORK

If you are designer and really planning to use ultralow power and lightweight wireless capabilities & solutions into your IoT ecosystem then the Microchip RN4020 is a straightforward suitable solution. Due to certifiable level of reliability and Bluetooth Version 4.1, it has been become popular in industry automation in specially supporting Industrial IoT applications. RN 4020 comes with mounted module having complete inbuilt protocol stack as mentioned earlier. To control it, ASCII commands are used with the help of UART interface [4]. To support custom data, Microchip Low-energy Information Profile (MLDP) in addition to SIG profiles are available to the developers. Developers can easily use spotlight attribute without intervention of microprocessor to achieve speedup. This module can be easily under controlled by other device/module through secured connection and easily upgradable with the help of over the air programming [4].

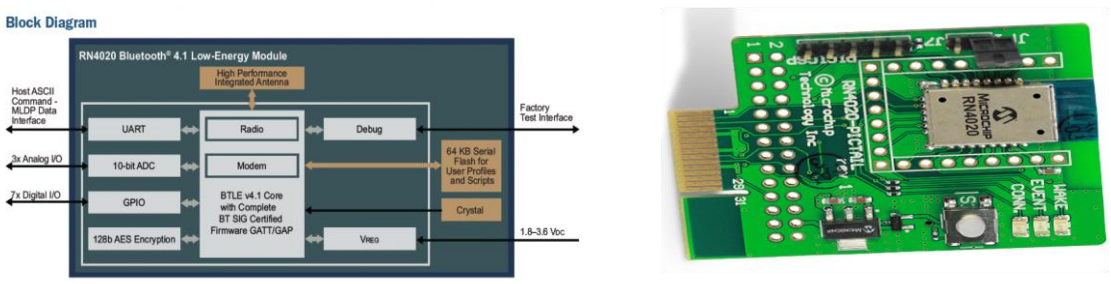


Figure: 2 Block diagram of Microchip RN4020 module [4]

The long range antenna outer perform in covering range (almost more than 100 meters with the help of PCB type antenna), its compact size is best suitable to make scope to get integrated and make lightweight applications. (In terms of dimensions; Module is of 11.5 x 19.5 x 2.5mm). This module can easily become integral part of any cost effective microcontroller for energy efficient applications.

One another device popularly known as IBeacon from Apple is found to be a complete solution with BLE stack. It is especially intended to design and provide broadcasting facility which provides self-identity of that BLE device with sequence number. This device is very helpful to iOS centric applications. Airport lounges of UK (with the help of BA and Virgin) are well equipped with lightweight solutions after having additional iBeacons installed and automatic boarding card detection application. This system can easily detect your boarding pass when you walk into the couch, and provide Wi-Fi usage information to passenger for that particular day.

In [3], Saminath.V & Jung Su presented the experiments using WICED Sense App on Android platform where WICED kit was utilized to check the effect of low energy connectivity with device. They developed the peer to peer system where connectivity is established and tested between WICED module and IOT foundation sever. This system use MQTT as application layer protocol to construct data transportation mechanism for IoT systems. The main drawback of this proposed implementations is that it offers only sensing utility band does not offer actual data transfer (SEND/RECEIVE) any type of data and hence one way communication is built in present work proposed by authors.

Survey of Bluetooth and Applications [11], authors Arwa Kurawar et al. described all the different Bluetooth standards with its comparative advantages and disadvantages, also its kit and network building such as MANET using Bluetooth technology. Communication of the devices and transferring the data such as text and images within network implementing secure connection with its protocol stack.

Artem Dementyev, Steve Hodges et al. [12] had analyzed the fact that the BLE protocol, ANT, and ZigBee usage is not that simple as they were used to analyze the consumption of power in a cyclic sleep node scenario. The paper also found out that BLE was the cheapest and efficient among all of them in order to achieve low energy consumption. The received, transmission and the sleep currents on an average along with data rate are given from the datasheet. Practically, they found that the power consumption in above communication technologies is not affected only by average data transmission but also depending upon the pattern of interaction between such devices. In addition to that, due to support of 6LoWPAN, we need to consider the extra burden of transmitting IPv6 headers even to exchange control messages over Bluetooth communication channels.

So, it is very essential to know that How Low Energy is Bluetooth Low Energy, and how we can Compare Measurements of traditional Bluetooth with Bluetooth 4.0. The power consumption was dominated by the parameters like the time that is used to reconnect after a sleep cycle and not the sleep or the active currents. This depended on the extent as to how much the RF module had slept that involved various RF packets. The energy consumption of the protocols that were analyzed changes. The changes were based on the things like the pocket size variations, the distances between the receiver and transmitter and the other hub parameters/ the fundamental energy consumption is given more concentration. The analysis of the energy intake of BLE is measured by the actual devices using a power monitor. The measurement outcomes gave rise to the various derived versions of the fundamental energy consumption. The things like the overhead of IPv6 based communication has to be looked into over the BLE. This has to be done for the relevancy of prospective IoT scenarios. Thus, one can see that it is very important to learn of how the Bluetooth Low energy is the actual low energy and the method of comparison between the traditional Bluetooth and BLE.

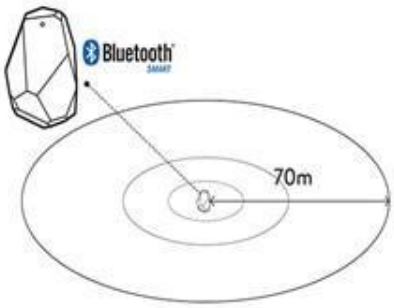


Figure 3: Signal range and measuring proximity [6]

Not just for low energy consumption, BLE works well for the Location Based Services too. The location-based services is not an alien or a relatively new concept, this particular locating job can be done by the receival of BLE packets. This includes more than a range of RFID and they do not have much capacity to support GPS or to scan Wi-Fi. Google introduced a comparable mechanism for the Android version 5.0. This was possible only on trusted devices and Android

Trusted Places. This would enable the android device to unlock itself if the device is in a trustworthy location. If the device is in the range of a reliable device, including a Bluetooth device, the Android device will unlock itself. The Google Physical Internet, its iBeacon drives out the URL through the BLE packets. The implementation of URIBeacon is very simple. This is very true if the ARM's embed framework is put to use and includes a Sample Code to get access and apply for various BLE applications like URIBeacon. The embed Account which comes as complimentary helps one to compose and compile the code from the embed interface.

There are various applications of the iBeacons that would require one to use a particular application at present. The first few questions about the Google Physical Internet introduction is like will the alarm cause a lot of disturbance. But one need not worry as one of the prominent features of the system is that there is no trouble for proactive notifications. The handset manufacturer who manufactures a device using a pre-installed iBeacons program enables the partners to drive the ads based on the location of the people. The Bluetooth can be turned off on your mobile phones and the iBeacons are the first ever BLE technology that one comes across as there are a larger number of devices that are already making using of this excellent technology.

Therefore, it becomes very essential to find out that the Low Energy is Bluetooth Low Energy and how the Bluetooth low energy is compared with that of the traditional Bluetooth. There are a number of companies and organizations are already using or experimenting with iBeacons. For example Major League Baseball for location tracking, Apple themselves for location awareness at an apple store, House of Fraser, Regent Street and Waitrose [9].

III. EXPERIMENTAL SETUP AND IMPLEMENTATION

With intention of energy modeling of Bluetooth 4.0 and traditional Bluetooth, first we tried to setup Tera Term for assessing BLE module. Before connecting RN4020 with Smartphone device, user may need to set up module using Tera Term software as follows:

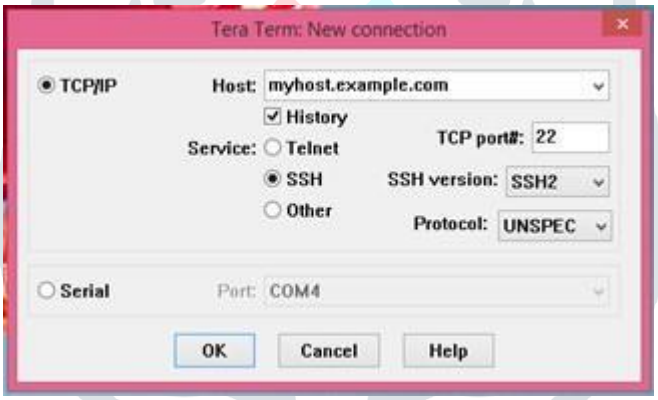


Figure 4: Tera Term Interface

Following set of commands in the Tera Term Terminal will be useful to setup an environment:

1. WAKE_SW pin high to enter Command mode.

2A27, 000D, V
2A26, 000F, V
2A28, 0011, V
2A29, 0013, V
2A24, 0015

2. Open terminal emulator that connects to the serial port of the RN4020 module with the following parameters

a. Baud Rate: 115200
b. Data Bits: 8
c. Parity: None
d. Stop Bits: 1

3. Issue the "+" command to turn on echo.

4. Issue the command SF, 1 to reset to the factory default configuration.

5. Issue the command SS,C0000000 to enable support of the Device Information and the battery services.

6. Issue the command SR, 00000000 to set the RN4020 module as a peripheral.

7. Issue the command R,1 to reboot the RN4020 module and to make the new settings effective.

8. After the RN4020 module has powered up and CMD is displayed on the terminal Emulator, issue the ”LS” command to display the current services.

Output:

```
180A
2A25, 000B, V
180F
        2A19, 0018, V
        2A19, 0019, C
END
```

After setting up BLE environment with module, it's time to accessing BLE module using Android interface that we used as shown in Figure 5:

Figure 5: Android Interface for BLE module Management

When the mobile node turn on the Bluetooth of the node and is in the network coverage of the BLE Module it will discover and notify its presence and then BLE Module will mark the Context(UID, status, data) of the Mobile node. The energy consumption of the process was extensive so we were in a position where we had to ensure our efforts would give less energy Consumption.

During Energy Modeling for measuring Energy Consumption in our work, we have first measured the Received Signal Strength Indicator (RSSI) value of transmission and received Signal between BLE Module and Mobile Node by Android Application. Received Signal Strength Indicator (RSSI) is a measurement of the power present in a received radio signal in decibels (dB), referenced to 1 milliwatt - dBM. Hence, that received signal strength is always measured in dBm as per Equation (1).

$$RSSI\ (dBm) = -10n\ log_{10}(d) + A \text{ --------[1]}$$

Where,
A = RSSI in dBm at 1 meter -you need to calibrate this on your system. Because you are calibrating at a known distance you don't need to take into account the frequency of your transmission and this simplifies the equation.
d = distance in meters
n = propagation constant or path-loss exponent (value 2 to 4)

Then after, obtained value of dBm is converted to the milliwatt. That milliwatt into the Joules. As we know that dBm or decibel milliwatt is an electrical power unit in decibels (dB), referenced to 1 milliwatt (mW). The power in decibel-milliwatt (P(dBm)) is equal to 10 times base 10 logarithm of the power in milliwatt (P(mW)) as per Equation (2):

$$P(dBm) = 10 \cdot \log_{10}(P(mW) / 1mW) \text{ -------[2]}$$

It is fact that the power in milliwatts (P(mW)) is equal to 1mW times 10 raised by the power in decibel-milliwatts (P(dBm)) divided by 10 as shown below as per Equation (3):

$$P(mW) = 1mW \cdot 10(P(dBm) / 10) \text{ --------[3]}$$

Which derive that 1 milliwatt is equal to 0 dBm and 1 watt is equal to 30 dBm (1W = 1000mW = 30dBm). For energy calculation, the consumption must be measured in Joule, hence Milliwatt to Joule conversion required, which is as per equation (4):

$$1 mW = 0.0010 J/s \text{ --------[4]}$$

IV. RESULTS AND DISCUSSION

In our experiment, we assumed that single BLE enabled device or smart objects connected for concurrent communication that means there are no concurrent connections as well communications possible for our work. All measurement and samples are collected for the duration of 10 Seconds. TABLE-I shows RSSI and power consumption observed through RN4020 module with the help of our Android App developed under prototype.

Distance (in Meters)	RSSI (in DBM)	Energy Consumption (in Joule)
0	-19.00	0.000012589
1	-66.00	$2.511886432e^{-10}$
2	-79.00	$1.258925412e^{-11}$
3	-84.50	$3.548133892e^{-12}$
4	-85	$3.16227766e^{-12}$
5	-88.50	$1.412537545e^{-12}$
6	-89	$1.258925412e^{-12}$
7	-93	$5.011872336e^{-13}$
8	-96	$2.511886432e^{-13}$
9	-96.50	$2.238721139e^{-13}$
10	-98	$1.584893193e^{-13}$
15	-101	$7.943282347e^{-14}$
20	-101	$7.943282347e^{-14}$
25	-102	$6.309573445e^{-14}$
30	-102	$6.309573445e^{-14}$
35	-104	$3.981071705e^{-14}$
40	-104	$3.981071705e^{-14}$
45	-105	$3.16227766e^{-14}$
50	-	-

TABLE - I Signal Strength and Energy Consumption by RN4020 module

On other side, the TABLE-2 shows readings obtained through Beacon module with the help of our Android App.

Distance (in Meters)	RSSI (in DBM)	Energy Consumption (in Joule)
0	-38	0.000000158
1	-73	$5.011872336e^{-11}$
2	-80	$1e_{-11}$
3	-87	$1.995262315e^{-12}$
4	-88	$1.584893193\ e^{-12}$
5	-90	$1e_{-12}$
6	-92	$6.309573445e^{-13}$
7	-92	$6.309573445e^{-13}$
8	-93	$5.011872336e^{-13}$
9	-95	$3.16227766e^{-13}$
10	-97	$1.995262315e^{-13}$
15	-97	$1.995262315e^{-13}$
20	-98	$1.584893193e^{-13}$
25	-99	$1.258925412e^{-13}$
30	-100	$1e_{-13}$
35	-100	$1e_{-13}$
40	-101	$7.943282347e^{-14}$
45	-102	$6.309573445e^{-14}$
50	-	-

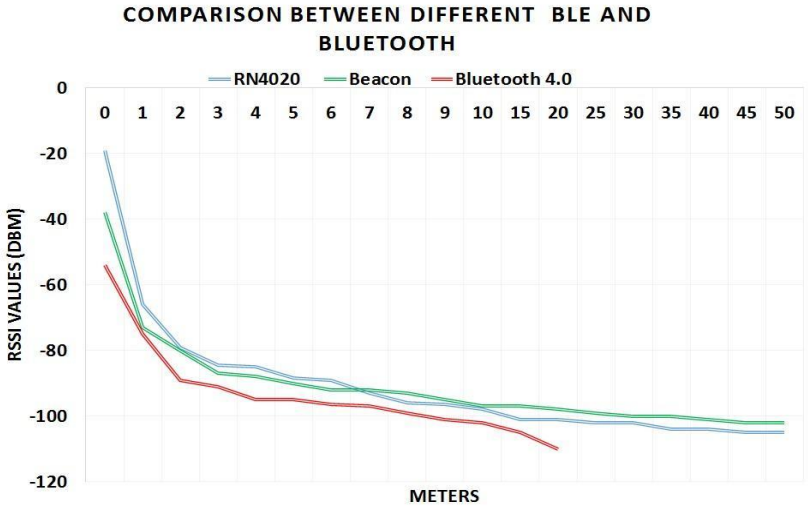
TABLE - II Signal Strength and Energy Consumption by Beacon module

We also evaluated the energy modeling and obtained results through Bluetooth 4.0 standard module with the help of same Android App as shown in TABLE-III to make comparative analysis amongst all available modern technologies more precisely to realize IoT ecosystem.

Distance (in Meters)	RSSI (in DBM)	Energy Consumption (in Joule)
1	-75	$3.16227766e^{-11}$
2	-89	$1.258925412\ e^{-12}$
3	-91	$7.943282347e^{-13}$
4	-95	$3.16227766e^{-13}$
5	-95	$3.16227766e^{-13}$
6	-96.5	$2.238721139e^{-13}$
7	-97	$1.995262315e^{-13}$
8	-99	1.258925412e-13
9	-101	7.943282347e-14
10	-102	6.309573445e-14
15	-105	3.16227766e-14
20	-110	1e-14
25	-	-

TABLE - III Signal Strength and Energy Consumption by Bluetooth 4.0 standards module

For various range, our experiment checked the signal strength and then converted them into Power consumption to perform Energy Modelling by various Bluetooth Low Energy standards and conventional Bluetooth. We also noted loss of connectivity of all modules with Smartphone App for the distance of 50 meters, whereas, in case of Bluetooth 4.0 Standards, we lost connectivity after 20 Meters.



Graph -I Power Consumption in various Bluetooth standards

This experiment and comparative measurements analyzed as shown in Graph -I proves that as compared to traditional Bluetooth, Bluetooth Low Energy standards are best suitable for energy efficiency and to prolong life time of our Future IoT Applications. This results also reveals that to demonstrate IoT ecosystem with smart object with such standards.

V. CONCLUSION

The BLE protocol stack provides the performance evaluation obtained with the help of this technology. This helps to explore the potential applications. It is also one of the reasons that in BLE, there is a tradeoff that involves energy consumption, latency, piconet size, and throughput. These depend on the ConnInterval and connSlaveLatency parameters. The evaluation results show how the parameters can be tuned accordingly that the requirements are fulfilled. The paper also points out the various other execution constraints that are present and that reduces the BLE performance in the real scenario. The comparison is made with the theoretically explained one. The BLE is a replica of the low cost powerful wireless technology that is used for single hop communications. The use cases contribute to the linking of a dramatically larger number of new devices into the domain of Internet of Things.

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