Bluetooth based Sensor Monitoring in Industrial IoT Plants

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***Abstract*—Internet of Things adoption in traditional and slow changing industrial plants such as power, water, oil-gas and chemical has proven to be beneficial in providing business value by transforming the way data is utilized in decision-making and visualization. Typical industrial IoT use cases involve acquiring data from sensor devices in plant and communicating the same to internet for local or remote monitoring and control. The sensor data acquisition in an industrial plant thus becomes paramount as the same acquired data is used for bringing out the underlying knowledge of system. IoT typically requires a local, low power wireless communication to acquire data from sensor devices and local gateway that is connected to internet for local or remote monitoring and control. This paper describes how Bluetooth low energy (BLE) technology can be used to connect sensor nodes to Internet-based services and applications using gateway in an industrial plant. It also investigates the performance of BLE technology as a local communication for sensor device monitoring.**

Keywords—Internet of Things, IoT, Bluetooth Communication, Sensor Monitoring, Device Monitoring, Bluetooth Low Energy, BLE, RSSI, Industrial Plants, device to device communication, m2m communication, Bluetooth measurement, Bluetooth performance.

I. *INTRODUCTION*

The Internet of Things refers to the networking among day-to-day objects or devices with internet enabled control system. It is the process of how various things which are connected to the internet interact with each other [1]. There are three steps in Internet of Things applications: capturing data from the object, aggregating that information across a data network and acting on that information. IoT is built on three major technology layers: Hardware (including chips and sensors), Communication (wired / wireless) and Software (including data storage, analytic and front end applications) [2].

Wide spread adoption of IoT has brought in a big change in a way the data is collected, stored and processed through novel techniques to produce the value in the best way possible. IoT has successfully penetrated in different domains and industrial plants is one such significant area.

Sensor device monitoring is an important aspect of IoT system. For an IoT system to be successful, it is necessary to have sensor monitoring systems in place, which would ensure that the devices are scanned at regular interval, their health is analyzed and any anomaly with respect to normal behavior is reported to user accordingly. Any monitoring system invariably performs following operations: security event detection, user notification in case of sensing parameter values crossing the specified normal limit and system alert notifications related to failure of devices or machines. While designing device monitoring systems, the care should be taken that the system architecture covers all the design aspects pertaining to above mentioned system functions and user gets informed accordingly[3].

The local communication network used to acquire data from device plays an important role in sensor monitoring system. There are many technologies such as Zigbee, Bluetooth, RFID, Infrared etc. that can be used for data acquisition purpose. The choice of Bluetooth technology for this work was partly driven by sponsored use-case in which the industrial devices to be used for this sponsored research project were already bluetooth enabled and partly because of bluetooth technology's inherent characteristics. Bluetooth wireless technology is a short-range communications system intended to replace the cable(s) connecting portable and/or fixed devices. Bluetooth is widely used technology for short distance communication in industrial network because of wide availability, low cost, low power and ease of deployment. Thus Bluetooth is prominent communication technology for sensor device monitoring [4].

This paper proposes an autonomous Bluetooth based field device monitoring system for a typical industrial plant and investigates the performance of Bluetooth network using various performance parameters. This paper also describes how most easily available and widely used Bluetooth enabled smart phones or tablets can be used in IoT infrastructure. The significance of this work is two fold. On one side it proposes, designs , implements and validates the autonomous sensor data acquisition scheme in IoT network which is the base for future

978-1-5386-9319-3/19/$31.00 ©2019 IEEE

autonomous systems in IoT. On the other hand it integrates bluetooth based communication technology with mobile applications for sensor monitoring as BLE is being widely employed in number of devices that are used in consumer, industrial domains. BLE based devices and their applications and users are increasing significantly every day. The performance assessment of such a communication framework is important to get buy-in from the industrial plant owners.

II. IoT for Industrial Plants

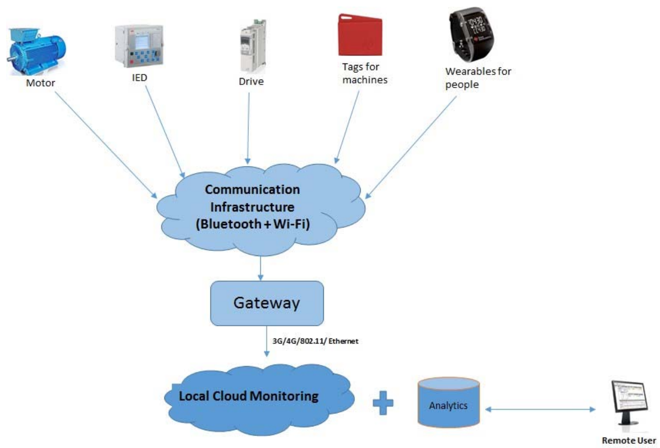

Fig. 1. Typical IoT System In Industrial Plant

Industrial plant owners face constant pressure to achieve the operational and business excellence. They continuously target to reduce the time to market. The growing expectations from industrial plants include smart and seamless assembly process, plant wide visibility of operations, visibility of equipment health, early identification of security threats, real time notifications of critical plant alarms, events, maintenance etc. However, the variability in plant systems, equipment, manufacturing process, intended functionality and external world interfaces pose huge challenges in terms of equipment interoperability, visibility and flexibility. Added to this, each plant has mix of new and old or traditional equipment to work with. All these parameters create barriers to achieve the goals of intelligent industrial plant operation.

The Internet of Things is changing this scenario. It provides with an opportunity for plant owners to continuously improve business innovation and operational excellence. The implementation of the Industrial Internet of Things, which connects industrial systems and equipment to internet services, makes automation smarter. Just like other domains, IoT can deliver next-generation operational intelligence, supplier quality, asset tracking, real time asset health monitoring and predictive analytics for industrial plants [5].

Fig. 1 shows typical IoT system in an industrial plant. The bottom layer of IoT system comprises of field devices or equipment such as robots, IEDs (intelligent electronic Devices), drives, motors, transformers etc. These are also called assets of plant, which are to be tracked or protected for seamless operation of plant. This warrants the asset related data to be acquired from field and sent to local or remote server for analysis. Typically, the device related data is acquired by local data acquisition unit on field and sent to local or remote server in control room using communication networks. One example of such data acquisition device is local communication gateway. Local or remote server is implemented using industrial level computers. Cloud based storage servers are also gaining lot of interest from plant owners for local or remote servers. The communication between sensor devices and on-field data acquisition unit is termed as local plant communication. Typical communication technologies used for local plant communication are Bluetooth, Zigbee, RFID etc. The communication between on-field data acquisition unit and local or remote server is called as remote communication. Typical communication technologies used for this communication are 3G/4G/802.11 etc. The data received at server is used to run various analytics services to make informed decisions. The server data can be accessed locally or remotely via internet. The output of analytics services is used for various plant related intelligent functions such as asset tracking, asset health monitoring, predictive maintenance etc.

Thus with the Internet of Things, plant owners can give each of their physical assets a digital identity that enables them to know the exact location and condition of those assets in real time. This information is further used to make informed decisions such as device replacement, device maintenance etc. IoT in industrial plant thus enables faster time to market, improved productivity and operational excellence.

A. Sensor Device Monitoring

With steep increase in manufacturing of devices that can exchange data internally or though internet, a huge population of devices that are connected to network is being enabled every year. The ever-increasing number of devices ensure that monitoring every device connected to the network manually is impossible. As internet adoption increased to employ more number of devices including wireless devices, more robust yet simple monitoring systems were employed. The monitoring systems were improved again to suit to cloud technology that has become stronger in last few years. With technology advances in wireless products and hand held devices such as mobile phones, it has become vital to come up with autonomous monitoring systems that are inter-operable with various types of sensor devices [3]. Mobile application based device monitoring systems are thus finding lot of popularity among IoT applications [6].

B. Local Communication Technology for Sensor Data Acquisition

The selection of local communication technology for sensor data capturing depends on operating environment, communication range, power requirement, cost, data bandwidth, physical size etc. An industrial plant IoT requires industrial grade, low power, low cost and physically smaller devices for monitoring and control system. Typical distance between sensor devices and gateway in plant is of the order of centimeters to few meters. Among other wireless communication technologies, Bluetooth was chosen for local communication as technical features were suitable for the application and the industrial sensing devices that we used for this sponsored research project were bluetooth enabled.

The key features of Bluetooth wireless technology are robustness, low power consumption, and low cost. Bluetooth Low Energy (BLE)[7] has become an important standard for different smart sensor devices, in industrial plant systems. BLE is a version of Bluetooth designed for lower-powered devices that use less data. BLE has the ability to exchange data in one of two states: connected and advertising modes. Connected mode uses the Generic Attribute (GATT) layer to transfer data in a one-to-one connection. Advertising mode uses the Generic Access Profile (GAP) layer to broadcast data out to anyone who is listening [8]. To conserve power, BLE remains in sleep mode except when a connection is initiated. This makes it ideal for power hungry applications such field device monitoring in an industrial plant. Another significant feature in Bluetooth low energy compared to other IoT wireless technologies is the support for smart phones and tablets.

III. BLUETOOTH BASED SENSOR MONITORING SYSTEM

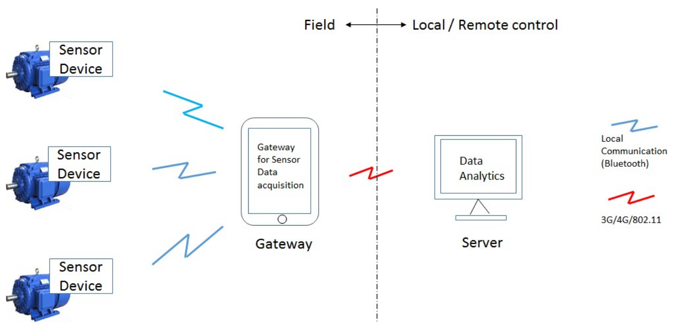

Fig. 2. *Bluetooth based Android app for sensor device data acquisition*

Fig. 2 shows an IoT system for field device monitoring using Bluetooth as local communication medium. Typical distance of data acquisition unit from field devices is in the range of few meters and bluetooth fits very well for such a requirement. Use of bluetooth communication in various IoT applications is growing due to its low cost, low power and easy to deploy features. Hence now a days, most of the field devices, sensors and gateways are found to be bluetooth communication ready. Bluetooth based on-field communication gateway captures the data from field devices. The gateway sends the data to local or remote server using cellular or 802.11 based communication technologies as the data range required for this communication is typically much more than that required for local communication. The data from server can be accessed locally or remotely using internet. The data from server is then analyzed for various applications to make informed decisions related to plant.

A. Autonomous field data acquisition

Typically Bluetooth communication is point to point.Present on-field bluetooth based data acquisition unit involves manual process to acquire data from field devices. The field person with bluetooth based acquisition unit forms connection with first device, acquires data and disconnects the first device. He then connects with next device and disconnects after data acquisition and the process follows till all field devices are covered. There is a lot of manual intervention involved in current bluetooth based data acquisition system.

As part of this work, we implemented a novel autonomous bluetooth based data acquisition system using mobile phone as gateway or data acquisition unit. A mobile APP was developed in smart-phone, which automatically searches the first device, forms connection, acquires data and disconnects the first device. It then searches for second device, forms a connection and disconnects second device after data acquisition on own. The autonomous process continues till all the devices are covered. Various features were implemented to improve the efficiency and reduce manual intervention such as continuously checking the availability of previously unavailable devices for data acquisition etc. This automation reduced the manual effort in data acquisition to greater limit.

IV. *PERFORMANCE MEASUREMENT AND ANALYSIS*

Along with inherent limitations of devices and data acquisition systems, external devices existing in plant can significantly influence the performance of local bluetooth communication [9]. This was given major consideration while selecting the performance parameters for bluetooth communication for field device data acquisition. Hence we selected RSSI, power consumption and communication latency as parameters that can affect the bluetooth communication performance. With the goal of testing the efficiency and performance of the bluetooh based local data acquisition one additional mobile application was designed to measure the performance parameters such as transmission latency, power consumption, sensor localization etc. The application has the ability to measure transmission time for each data packet from every sensor along with timestamp. The following sections describe them in more details.

A. Test Bed for Performance Measurement

Fig. 3 shows the test bed developed to assess the performance of autonomous bluetooth based data acquisition system. Currently the popularity of smart devices has grown increasingly due to rich application features, interactive user interfaces, wide communication options and ease of handling. With the increasing use of smart mobile or tablet in day-to-day life, it has become a crucial part of Internet of Things as well. Smart phones have all the features that are required for Internet of Things like Wi-Fi access point, Bluetooth, different types of sensors. Therefore, it is easier to use smart phone or tablet as gateway for data collection.

A prototype of bluetooth based data acquisition was implemented as a part of experimental setup in which smart device such as mobile or tablet was used as a gateway for acquisition of data from bluetooth based drive monitoring systems. A smart-phone based gateway had an Android application developed that collects data automatically and periodically from multiple drive monitoring units having bluetooth interface. It was achieved in polling manner for multiple devices. Data collected by the gateway was stored in the local device for analytics and visualization.

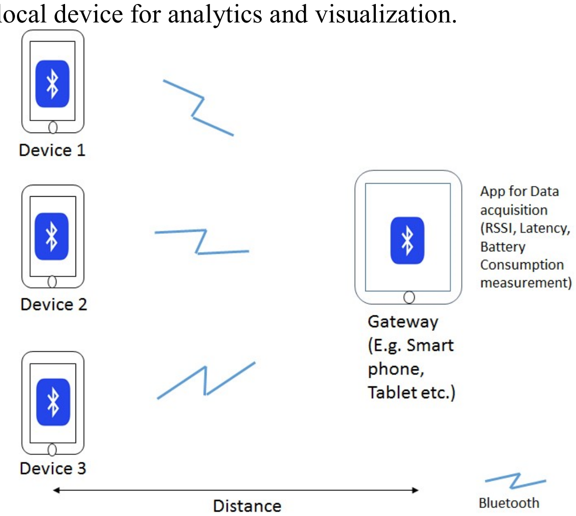

Fig. 3. Test Bed for Bluetooth Communication Performance Measurement

B. Communication Performance Parameters

Measuring the performance of bluetooth communication network was important to assess its applicability for sensor device data acquisition in industrial IoT plant. A smartphone gateway with autonomous data acquisition APP also had another APP to measure and store bluetooth performance parameters. The selected performance parameters have been described in detail below.

1) RSSI: Received Signal Strength (RSS, also called Received Signal Strength Indication, RSSI) indicates the power present in a received radio signal. It is measured from each received frame as average value measured during the first eight symbols (preamble) and converted to the RSS indicator [10]. RSSI can be used to estimate distance between smart devices [11]. The characteristic of Bluetooth RSSI value is different due to dynamic environments.

2) Power Consumption: Power consumption of BLE gateway is defined as the energy consumed by device for acquiring the data from sensor devices [12]. It can be expressed as energy in Jouls or as percentage of total energy consumed by device for data acquisition. IoT system would like to have low power consumption for all the subsystems.

3) Communication Latency: Communication latency is defined as the time delay between data transmitted from a sensor device and its availability at receiving gateway (e.g. smart phone) for further processing. For critical applications, the latency has to be low so that the data can be made available faster at local or remote control for decision-making. For monitoring applications, this requirement is not considered stringent.

C. Performance Analysis

We conducted number of experiments to measure the performance parameters namely RSSI, power consumption and communication latency. The entire measurement process was automated in order to save the manual effort in conducting experiments and measuring the readings. The experiments were conducted indoor (i.e. inside laboratory where environment was controlled) and outdoor (i.e. out of building where environment was uncontrolled). The analysis of performance parameters based on measurements has been outlined below.

1) RSSI: RSSI values were measured for each of the field devices keeping smartphone gateway at a distance of 1 meter, 3 meters, 5 meters, 10 meters, 15 meters and 20 meters.

Band of RSSI values for a particular distance: On contrary to to expectation of single RSSI value for a particular distance, it was observed that the RSSI values drift in a range for a particular distance. Fig. 4 to Fig. 7 show the variation in RSSI values in indoor environment for 1 meter, 5 meters, 10 meters and 15 meters respectively. For example, the variation in RSSI for 1 meter distance is from -57 to -61 dBm whereas it is from -75 to -82 dBm for 15 meters distance. There is always a band of 5 to 6 dBm in RSSI measurement for a particular distance. The variation in RSSI is due to environmental influence on RF communication. However taking large number of sample measurements and employing statistical techniques, the closest RSSI out of sample space can be selected.

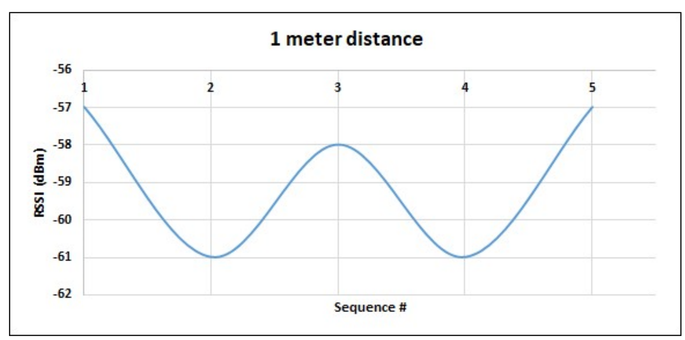

Fig. 4. Range of RSSI values for 1m distance

RSSI vs Distance: RSSI is a key parameter in localization and estimating the distance of an object. The closest RSSI value from measured range of values was calculated using statistical techniques. Figure 8 and 9 show the relationship of statistically estimated RSSI and the actual distance in controlled indoor and uncontrolled outdoor environment. It can

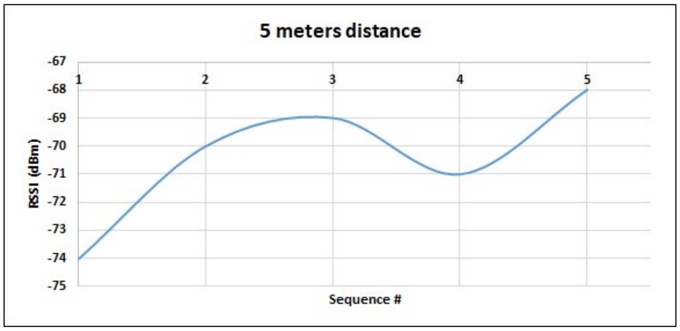

Fig. 5. Range of RSSI values for 5m distance

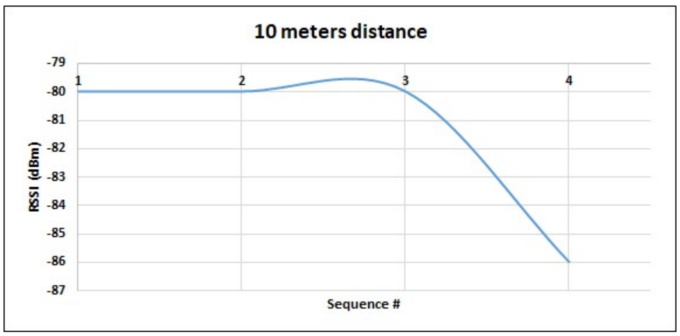

Fig. 6. Range of RSSI values for 10m distance

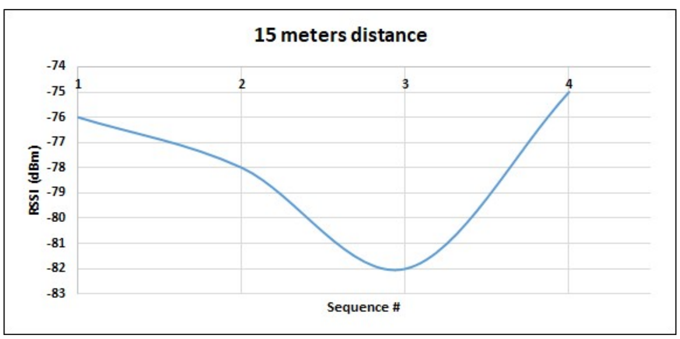

Fig. 7. Range of RSSI values for 15m distance

be seen that RSSI follows a decreasing trend as the actual distance increases.

The calculated RSSI value was used to estimate the distance based on the triangulation methods [10] [11].

Fig. 10 shows the comparison of actual and estimated distance in controlled indoor environment. The estimated distance based on RSSI values matches closely with actual distance up to distance of 25 meters. The figure also indicates error in actual distance estimation. For indoor it is less than 1 meter for actual distance up to 15 meters. Fig. 11 shows the actual vs estimated distance in an uncontrolled outdoor environment. The estimated distance based on RSSI values matches closely with actual up to distance of 20 meters. The figure also indicates error in actual distance estimation. For outdoor, it is less than 2.7 meters for

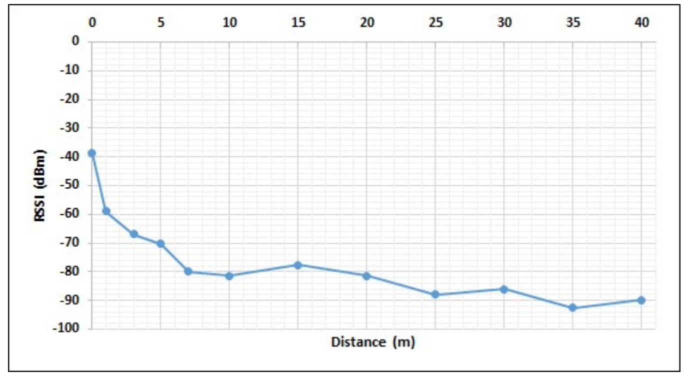

Fig. 8. Indoor : RSSI vs Actual Distance

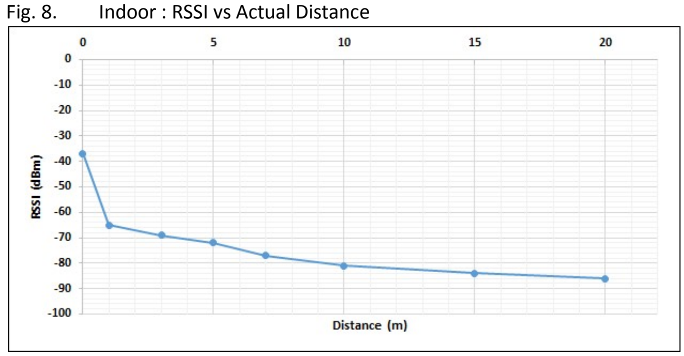

Fig. 9. Outdoor : RSSI vs Actual Distance

actual distance up to 15 meters. This proves that the our smart-phone based data acquisition system can estimate the distance between field device and data acquisition unit i.e. smart-phone gateway up to 20 meters in indoor and 15 meters in outdoor environment with certain minimal deviation.

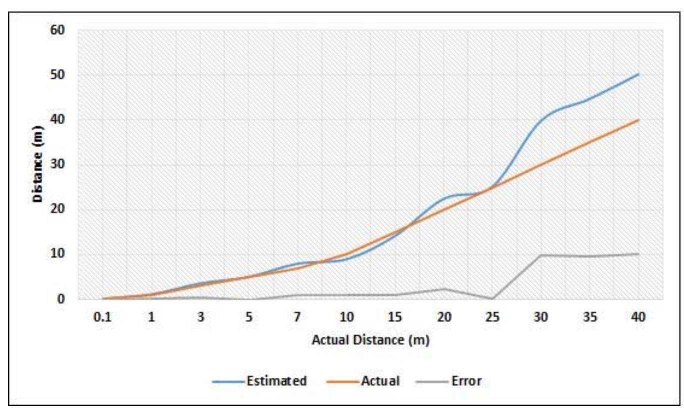

Fig. 10. Indoor : Actual vs Estimated Distance

2) Power Consumption: We performed a detailed analysis of energy consumption of a smart phone that was acting as a gateway. We showed how the different components and applications within smart phone contribute to overall power consumption. The multiple experiments indicated that

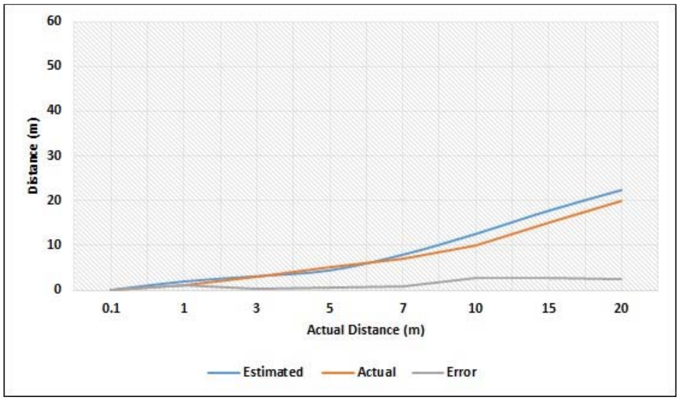

Fig. 11. Outdoor : Actual vs Estimated Distance

the sensor data acquisition application residing on smart phone consumes less than 2 mWh energy (mean = 1.63 mWh, standard deviation = 0.22). The contribution of sensing application is within 2 percent (mean = 1.69 percent, standard deviation = 0.11) of the aggregate consumption.

3) Communication Latency: The custom mobile application undertook multiple readings of communication latency by placing gateway having sensing application at various distances (1-15m) from sensor devices. The analysis shows that the latency for distance up to 15m is always less than 76ms (mean = 34.96ms, standard deviation = 20.92).

In general, the Bluetooth based data acquisition unit implemented using smart phone gateway was found to be very robust as concerned to RSSI, power consumption and latency. The performance was satisfactory in an environment where we typically find few tens of external devices that can interfere with bluetooth communication performance.

V. *CONCLUSION AND FUTURE WORK*

This paper presented Bluetooth based autonomous sensor device monitoring system for industrial plants. Bluetooth was used as local communication for sensor data capturing. The performance of BLE as local communication technology for sensor data capture was measured using a test bed. The performance of BLE communication network was measured in controlled indoor as well as uncontrolled outdoor environment conditions. The analysis indicated that the Bluetooth fares well the industrial plant sensing application up to 20 meters range with minimal or acceptable deviation in performance. Bluetooth also performs well in other performance indicators due to low communication latency and low power consumption.

While this study focused on Bluetooth technology for sensor monitoring, the framework can be used to assess the other communication technologies such as Zigbee, RFID etc. and compare the results. However this was not part of scope for this work. This study included prominent performance parameters related to undertaken use case to analyze local communication technologies. However various other parameters such as bandwidth, node density, effective usage of zone/backbone, storage etc. are not considered for this study. Security is becoming increasingly important and so also for industrial plant IoT. Based on the use case, the additional relevant parameters can be used for future performance assessment of industrial plant communication.

REFERENCES

[1] Rose, Karen, Scott Eldridge, and Lyman Chapin. “The Internet of Things: An Overview ”, 2015.

[2] Knud Lasse Lueth, “IoT basics: Getting started with the Internet of Things”, http://iot-analytics.com/wp/wp-content/uploads/2015/03/2015March-Whitepaper-IoT-basics-Getting-started-with-the-Internet-ofThings.pdf.

[3] Gupta Udit, “Monitoring in IOT enabled devices”, arXiv preprint arXiv:1507.03780 (2015).

[4] Andersson, Mats, “Use case possibilities with Bluetooth low energy in IoT applications.”, White Paper (2014)

[5] Yang, Chen, Weiming Shen, and Xianbin Wang, “Applications of Internet of Things in manufacturing”, *IEEE 20th International Conference on Computer Supported Cooperative Work in Design*, CSCWD, 2016

[6] Tharinda Nishantha Vidanagama, “Towards realization of an IoT environment: A real-life implementation of an IoT environment and its analytics”, *Global Internet of Things Summit*, GIoTS, 2017

[7] “Bluetooth.org, Core specification v4.1”, https://www.bluetooth.com/ specifications/bluetooth-core-specification.

[8] “Bluetooth.org, Supplements to the Core Specification (CSS) v.4”, https: //www.bluetooth.com/specifications/bluetooth-core-specification

[9] Treurniet, Jan Jaap, et al., “Energy consumption and latency in BLE devices under mutual interference: An experimental study”, *3rd International Conference on Future Internet of Things and Cloud*, FiCloud, 2015.

[10] Botta, Miroslav, and Milan Simek, “Adaptive distance estimation based on RSSI in 802.15. 4 network”, Radioengineering 2013

[11] Wang, Yapeng, et al, “Bluetooth positioning using RSSI and triangulation methods”, *IEEE 10th Consumer Communications and Networking Conference*, CCNC, 2013

[12] Kyung Kwon Jung, Yong-Joong Kim, “Design of smart monitoring system based on bluetooth low energy”, *International Conference on Electronics, Information, and Communication*, ICEIC, 2018