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Internet of things based sensing system for substation automation in smart grid environment

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Abstract

Substation Automation is a key concept in Smart Grid Technology. The present work proposes an Internet of Things (IoT) based system for the monitoring, visualization, storage and analysis of sensor data in an easy, cost effective and reliable manner. MQ Telemetry Transport (MQTT) protocol is used to communicate and transfer data between different sensor nodes using Raspberry Pi 3 as the MQTT broker. The sensor nodes are capable of wirelessly transferring the sensor data using an Arduino Uno and ESP8266. The sensor data can be conveniently accessed by any device on the network from the MQTT broker by subscribing to it. The given sensing system intends to complement and enhance the capabilities of the present substation automation environment. It incorporates the possibility of remote accessibility and better data analysis of the sensor data in the Substation environment. An Arduino sensor node with wireless capability has been tested and reported as a part of the ongoing implementation of the system which will be described in further works.

Keywords: Internet of Things, Substation Automation, Smart Grid, MQTT, Arduino, Raspberry Pi.

Introduction

The Smart Grid technology is expected to change the face of the Electrical grid by the integration of new solutions to manage the Power system infrastructure reliably and intelligently. It aims at improving the power reliability, quality and efficiency of the existing grid. It is achieved by automating the maintenance and operation and the deployment of Renewable and distributed energy sources. The overall objective of the smart grid is the smart and optimal utilization of all the available resources[1-3].

Substation plays an integral role in the electrical generation, transmission and distribution system. Substation technology is continuously evolving to accommodate with the challenges presented by the more digitized and decentralized power distribution systems. The evolution of Distributed Energy Systems is also a reason why the substations need to adopt new technology. The deregulation of the power industry has led to an increased emphasis on Substation Automation for the emerging Smart Grid Environment[4].

The use of intelligent devices, powerful substation computers, equipment knowledge modules and local storage could prove to be essential for the implementation of smart substations. The new assets must meet the technical requirements of the substation as well as be safe, secure, easy to use, configure and easily updatable for any future changes. The substation equipment should reduce the unscheduled downtime and increase the reliability of the system. For example, shifting from time based monitoring to condition based monitoring will allow to optimize the investment and maintenance costs. All the communication devices for substation automation should allow easy, sustainable and vendor agnostic exchange of the engineering data and built according to IEC61850[6,7].

Condition monitoring of the various equipment in a substation gives an overall picture of the state of the various components in the substation. The manual monitoring of the substation equipment is prone to human error and may reduce the system response speed which are critical in building an efficient monitoring system. These limitations can be overcome by condition based maintenance of the substation using online measuring instruments. The measured information can be transmitted and stored to a central location for easy remote monitoring and analysis[6,8].

In the present Substations, Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCS) are the most widely used standards for Substation Automation and control. With the recent advances in the Internet of Things (IoT), all the sectors have seen a big shift towards smart connected things. Connectivity and information exchange have become a common feature in the everyday objects. In this regard, the substations also need to make a move to Internet of Things. IoT has proven to be complimentary with SCADA as the information gathered by SCADA systems can act as one of the data sources for the IoT. While SCADA focusses on monitoring and control, IoT focusses on monitoring, acquiring and analyzing the machine data to improve productivity.

The SCADA systems work perfectly for day to day monitoring of what is going on in the substation whereas the IoT solutions have the ability to address macro level questions such as the operational effectiveness across various sub systems, the process changes to improve performance, prediction of failures and planned and actual comparisons. These questions are of high relevance to the managers, planners and supervisors in the Substation environment. Hence, implementation of IoT alongside the present systems is expected to enhance the robustness, efficiency and convenience in the substation[9].

The present work emphasizes on the use of Open Source hardware for implementation for a faster cost effective and convenient integration of IoT technologies in the present Smart Grid Environment[10]. The Open source environment has numerous advantages apart from being cheaper than the commercially marketed products. These hardware and software are highly reliable in the sense that they have been developed by skillful experts who are continuously working on improving them and have been tested by tens or hundreds of people. Open source environment is mostly vendor agnostic Thus, unique and innovative infrastructure can be created to suit the needs of the required application. Some disadvantages of the open source such as malicious users and lack of extensive support can be easily addressed for an application area like Substation automation by the use of private networks and creations of special network of skilled people within the area. Also, support individuals and groups may be easily hired to address the support issues. Once the open source environment is setup, the cost effectiveness, high reliability and faster integration can prove to be beneficial in the development of smarter substations in the Smart Grids.

The present work proposes a systematic design approach for sensor management in substation using IoT[11]. The design describes a system to handle the sensor data at all levels using MQTT protocol over a wireless network[12,13]. An Arduino based senor node capable of sending data wirelessly using the ESP8266 Wi-Fi chip is tested as a prototype[14]. MQTT communication protocol has been used to transfer data. MQTT is a lightweight and reliable messaging protocol with implementations for many different platforms[15]. The Raspberry Pi is used to host the MQTT broker to further the sensor data to other devices. The system provides a flexible solution to collect, process and save data from sensors on different hardware platforms.

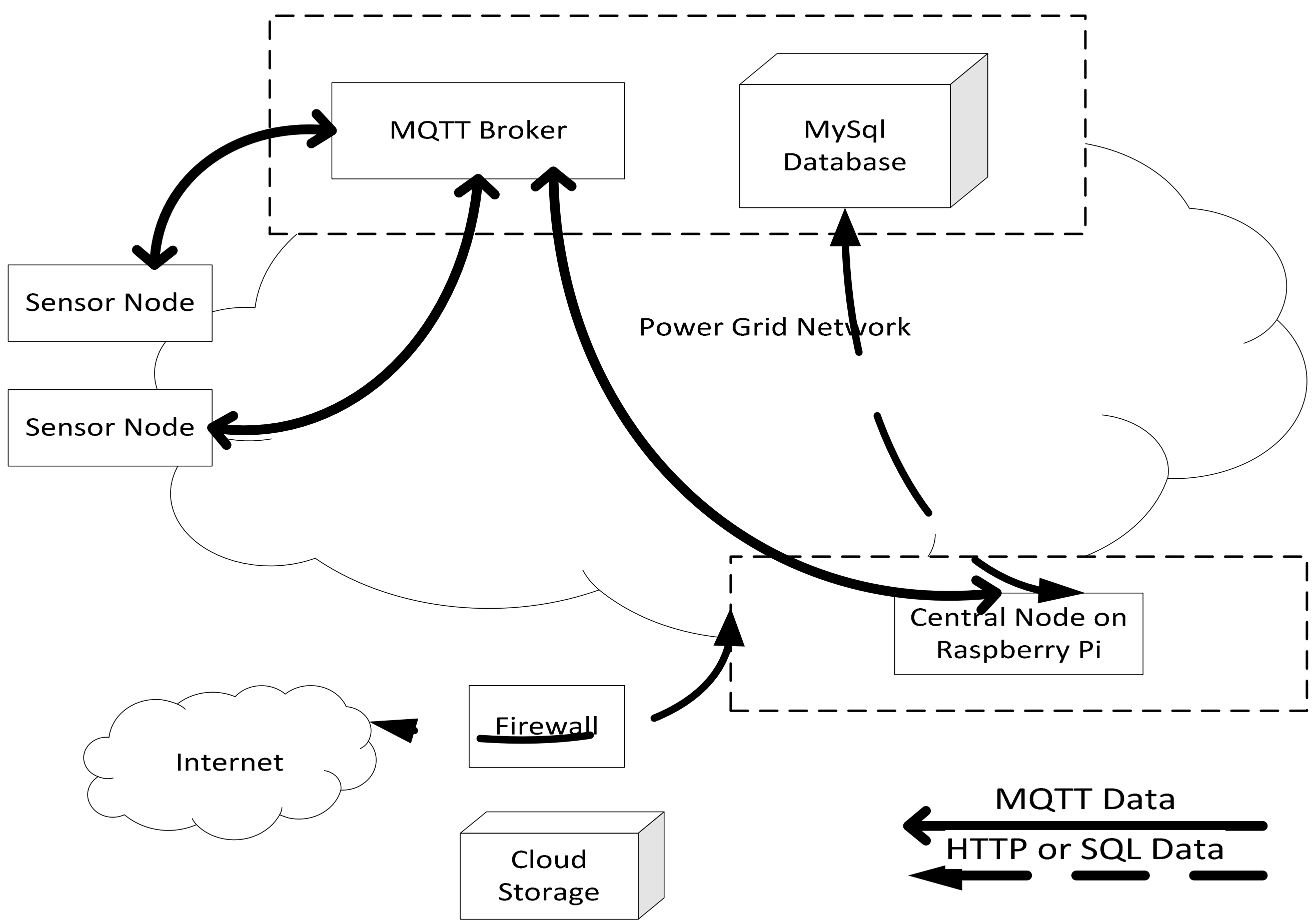


Figure-1: Overall architecture of the proposed sensing system.

System Description

Figure-1 shows the network and hardware setup and the data streams.

The hardware setup includes: i. The central node which can be implemented using a Raspberry Pi device. ii. A 24/7 active server which can run a Mosquitto MQTT broker and a MySql database. iii. An Arduino sensor node capable of transferring the sensor data wirelessly to the MQTT broker and the central node.

The data streams are: i. Sensor Data: MQTT messages from sensors node to central node over MQTT broker, ii. Processed measurement data from the central node to MySql database and Cloud storage.

The various parts of the system are described as follows:
Sensors and sensor interfacing: The substation environment consists of a variety of sensors for monitoring a number of parameters such as temperature, pressure, humidity, vibration, gas density, leakage current etc. The output of these sensors are generally expressed in the 4-20mA signaling standard due to its proven robustness. Other type of sensors can be RF sensors and Fiber optic sensors. It is required to properly interface these sensors to make them compatible for the IoT environment.

The 4-20mA sensors can be easily interface using current loops to provide a voltage output which can be used as an input to the IoT device such as Arduino. Using current loops for data transmission is ideal because they are inherently insensitive to electrical noise. Figure-2 shows the schematic of a basic 4-20mA current loop. There are mainly four components: i. A DC power supply, ii. A 2-wire transmitter: It converts the real world signal such as temperature, pressure etc. into the necessary control signal for the current loop. iii. A receiver resistor that converts the current signal to a voltage: It is more convenient and easier to measure voltage than current and so it is used to produce a voltage that is easily measured by analog input of the controlling device. iv. The interconnecting wire.

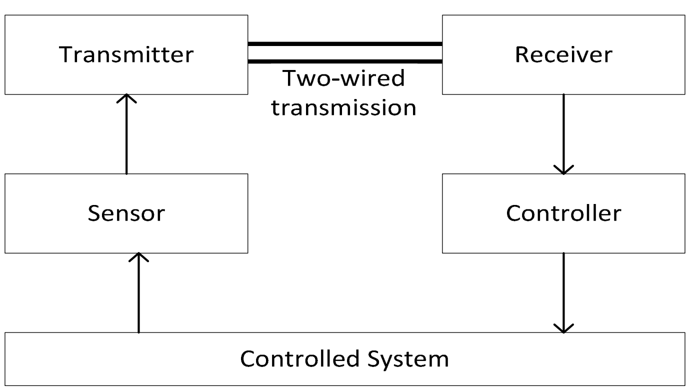


Figure-2: A basic 4-20mA current loop.

The RF sensors and Fiber optic sensors can be interfaced with the IoT hardware such as the Arduino using RF shields and fiber optic connectors that are easily available. There are a diverse set of adapters and connector that can connect to machines, SCADA and DCS.

Thus, the IoT devices can be conveniently interfaced with the sensors using appropriate hardware which can be procured or built easily using simple hardware.

Sensor nodes: A sensor node is a small and inexpensive device with on board capabilities to process, power and communicate sensor data wirelessly. It also contains limited memory and power resources. Here a sensor node using an Arduino Uno and ESP8266 Wi-Fi chip is suggested.

Both of the suggested hardware are cost effective, small in size and provide multi-functionality to transfer the sensor data wirelessly with good reliability. Figure-3 shows a schematic for a sensor node.

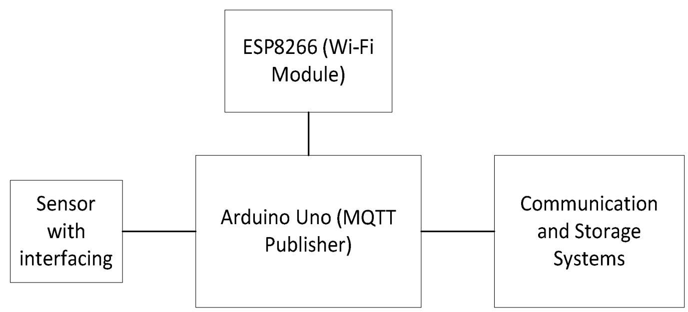


Figure-3: Schematic diagram of the sensor node.

The Arduino Uno is an open source micro-controller board based on the ATmega328. It comes with both analog and digital input/output pins and can be easily powered using a USB connection. It can be conveniently programmed using the Arduino IDE. It is a widely used board with ample support available. The raw sensor data can also be processed up to some extent at the sensor node itself before further transmission.

The ESP8266 is a very small and cheap Wi-Fi module which can be easily programmed to send sensor data wirelessly with low power consumption. It can double as an application processor using its Built-in-low power 32 bit CPU. It means that it can function as a standalone device once it has been programmed. Although, here it recommended to use in conjunction with the Arduino for better robustness and reliability in the substation environment.

The sensor node based on Arduino supports the MQTT messaging protocol and hence can send MQTT data wirelessly over the TCP/IP protocol.

MQ Telemetry Transport (MQTT): MQTT is a Client Server publish/subscribe protocol. It is ideal for use in constrained environments with low processing requirements and /or the network bandwidth is at premium. It is an ideal for industries, machine to machine communication, power grids where the data to be transferred is generally small and time sensitive.

Figure-5 shows the MQTT publish/subscribe model. It uses publish and subscribe pattern (pub/sub) is an alternative to the conventional client server model. In MQTT, the client, who is sending a message (Publisher) and the client who is receiving a message (Subscriber) is decoupled by Pub/Sub unlike the Client Server model where the client communicated directly with an end point. A third component called broker connects both publisher and subscriber and filter all the incoming messages and distributes them accordingly. In this way, the publisher and subscriber are unaware of each other's existence.

The MQTT protocol embodies all the aspects of the Pub/Sub model and consists of two components the Client and the Broker. It is based on top of TCP/IP and both client and broker must have a TCP/IP stack.

It has three Quality of Service (QoS) agreement levels between the receiver and sender regarding the guarantees of delivering a message. They are: QoS 0, QoS1 and QoS 2 referring to at most once, at least once and exactly once respectively. QoS is important because it provides greater reliability in communication and guarantees the delivery of data regardless of the how unreliable the underlying transport is.

MQTT is an ideal protocol for communication in Substation environment for sensing data where reliability is a priority.

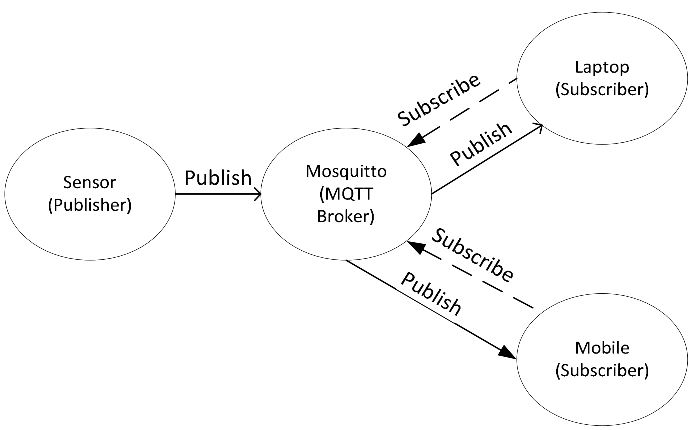


Figure-4: Publisher/ Subscriber model for MQTT protocol.

MQTT broker: The MQTT broker is a server device that can host any one of the several MQTT clients available to facilitate the transfer of MQTT data as and when requested by the subscribers. The size of the server depends on the number of clients it is expected to serve. Mosquitto is a reliable and frequently used MQTT client available on a variety of platforms. For test purposes Mosquitto can be hosted on a Raspberry Pi. Although for Substation environments dedicated servers can be used to host the broker client as well as for storing the data.

Data Storage: The data can be stored locally in a MySql database as well sent to a Cloud server where interactive visualization of the data can done. This allows remote access of data as well as condition monitoring of data from a remote location.

The Central Node: It is responsible for processing and storing the incoming MQTT messages from the sensor node. The central node decides the behavior of the MQTT data as to how the measurements are to be sent, processed and where the processed data should be stored. Raspberry Pi is the recommended hardware for the central node since it is a small and powerful processing device with low power consumption and supports many programming languages making it easier and efficient to handle the data. Data processing is done to reduce and to retain the minimum data points required for further analysis of the data as well as to save the storage space.

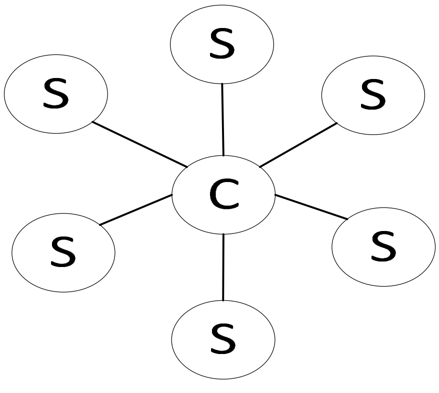
Thus, a cost effective decentralized sensing system with remote access to data for analysis within the substation has been developed.

Furthermore, the reliability and access of the system can be enhanced by: i. Selecting a suitable network topology for the sensor nodes, ii. Bridging the MQTT brokers to establish communication between various substations, iii. Selecting a suitable network for the Substation, iv. Implementing proper security protocols.

The above objectives can be achieved as described below:

Selecting a suitable network topology: The Substation is spread over a large area and hence the sensors are distributed all over the substation so a suitable network topology must be selected to ensure complete and reliable coverage. To achieve this a Star topology network can be beneficial in which Sensor subsystems can be deployed. The sensor subsystem can serve a dedicated number of sensor nodes distributed around the MQTT broker server and the Central node as shown in Figure-5(a). This will allow a particular sensor node to be located in the range of the broker and central node as well as distribute the network load. The various central nodes can then send their data to a common Master node as shown in Figure-5(b). For the Sensor subsystems the Broker devices used can be relatively smaller and hence cheaper to make the system cost effective. Also, similar type of sensors can be grouped to in the same sensor subsystem to allow easier setup.

Bridging MQTT brokers: Mosquitto (and some other MQTT brokers) lets you connect two or more brokers together using a feature called Bridging. Figure-7 shows how bridging is done. If we want to share information while maintaining the privacy on both sides then it can be achieved by bridging. Using this feature only relevant information allowed by a broker can be easily and securely accessed. This feature uses Transport layer Security (TLS) to protect credentials and data in transit. The sharing of data can be controlled using an Access Control List (ACL) setup by the broker. ACLs ensure only that data is shared which is agreed upon. Using user authentication on both sided requested data can be shared.



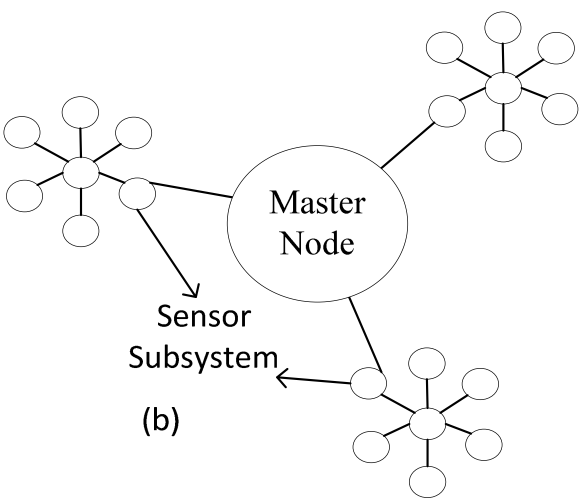


Figure-5: (a) Suggested network topology for the sensor nodes C=Central Node with MQTT broker S=Sensor Node (b) Suggested network topology for the sensor subsystems.

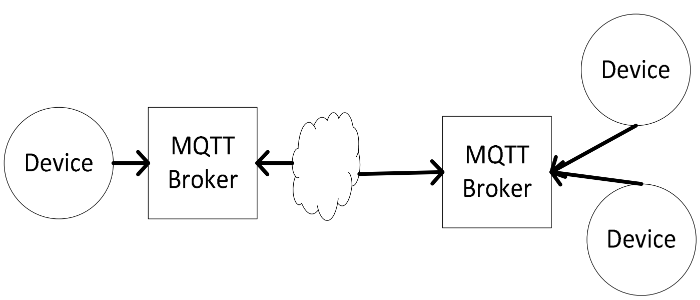


Figure-6: Bridging of two MQTT brokers.

This feature can prove to be useful when there are a lot of Distributed Energy Resources (DER) present. Since the Smart Grid technology encourages the integration of Non-conventional energy resources, Distributed Energy resources have become very common and integral to the Smart Grid Environment. It is not be possible to setup separate Substations for each of the DERs so bridging of MQTT brokers can prover very useful to share information between DERs and substations provided the DERs are enabled by the MQTT protocols.

Selecting a suitable wireless network: Wireless communication technologies such as Public Wireless Network, Power Private Network, Wireless Mesh Network and Low Power Wide Area Network are widely used in power grid communication. However, a single technology cannot suffice all the requirements of the power grid and the same can be said for substations. Due to a variety of application principles, different technologies must be appropriately and used in the substation.

The Public Wireless Communication has low cost but is also low on reliability and hence it must not be used for transfer of critical. Although it can be used for remote access and transfer of time insensitive and non-critical data to save costs. The Power Private Wireless network is a dedicated network for the Power grid enterprises and provides high reliability. However, the signal coverage is limited to the area in the substation. This network can be effectively used for communication within the substation. The Wireless Mesh Network has the self-healing network ability but its planning and installation is a complex task for the complete substation environment. This network can be used to connect the various central nodes of the sensor subsystems in the system described in Figure-5. The Low Power Wide Area network can be used to connect the various sensor nodes in a sensor subsystem as it has low power consumption, increase the signal coverage. The LPWAN must be tested first for suitability of the sensor node in use as it as low throughput and high time delay.

Thus, multiple type of communication networks suitably selected can optimize the overall communication network of the substation.

Implementing proper security protocols: The communication infrastructure of any Substation Automation System is prone to security threats at various levels. The security protocols must be implemented in the development phase itself to validate the authenticity of messages and prevent intrusions. The main concern of the IED (Intelligent Electronic Device) developed is that the microprocessors deployed have little processing capabilities and hence are potentially open to threats.

The MQTT protocol used in the proposed system has an authentication function at the client broker level. It employs a Transport Layer Security (TLS) protocol to protect the integrity of the data in transit. TLS has many methods of encrypting data and authenticating message integrity.

A detailed system design approach is hence discussed in this section which can be tested in real time using smaller prototypes.

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Experimental

Arduino based Sensor Node Prototype: Implementation of the system described in the previous section is in progress. As of now an Arduino sensor node was tested to control an LED using Internet as a prototype to control a sensor. The Arduino node consist of an Arduino Uno, ESP8266 and interfacing circuit for the ESP8266. Figure shows the circuit developed of the developed node. The ESP8266 requires a 3.3V power supply which was obtained using AMS1117 and 2 capacitors (470µF each) from a 9V DC battery. To connect the TX and Digital Out pin two voltage dividers are used. They were made using 10kΩ and 20kΩ resistors to shift the 5V logic to 3.3V. The ESP8266 was then connected to the Arduino and a simple code was written to setup an internet gateway on the home Wi-Fi network to display the status of the LED and change its state. The code is written and flashed using Arduino IDE. The Raspberry Pi was setup and an MQTT broker is successfully tested to publish and subscribe using a simple test routine. Further work includes connecting the Raspberry Pi with the Arduino sensor node and using it to obtain the sensor data wirelessly using the MQTT protocol and publish the data to various devices as well as store and visualize the data on the cloud and a MySQL database. The system can also be tested using multiple sensor nodes to check the reliability and range. After the testing of the prototype of the system an attempt will be made to test the system in real time in Substation environment subject to availability of resources.

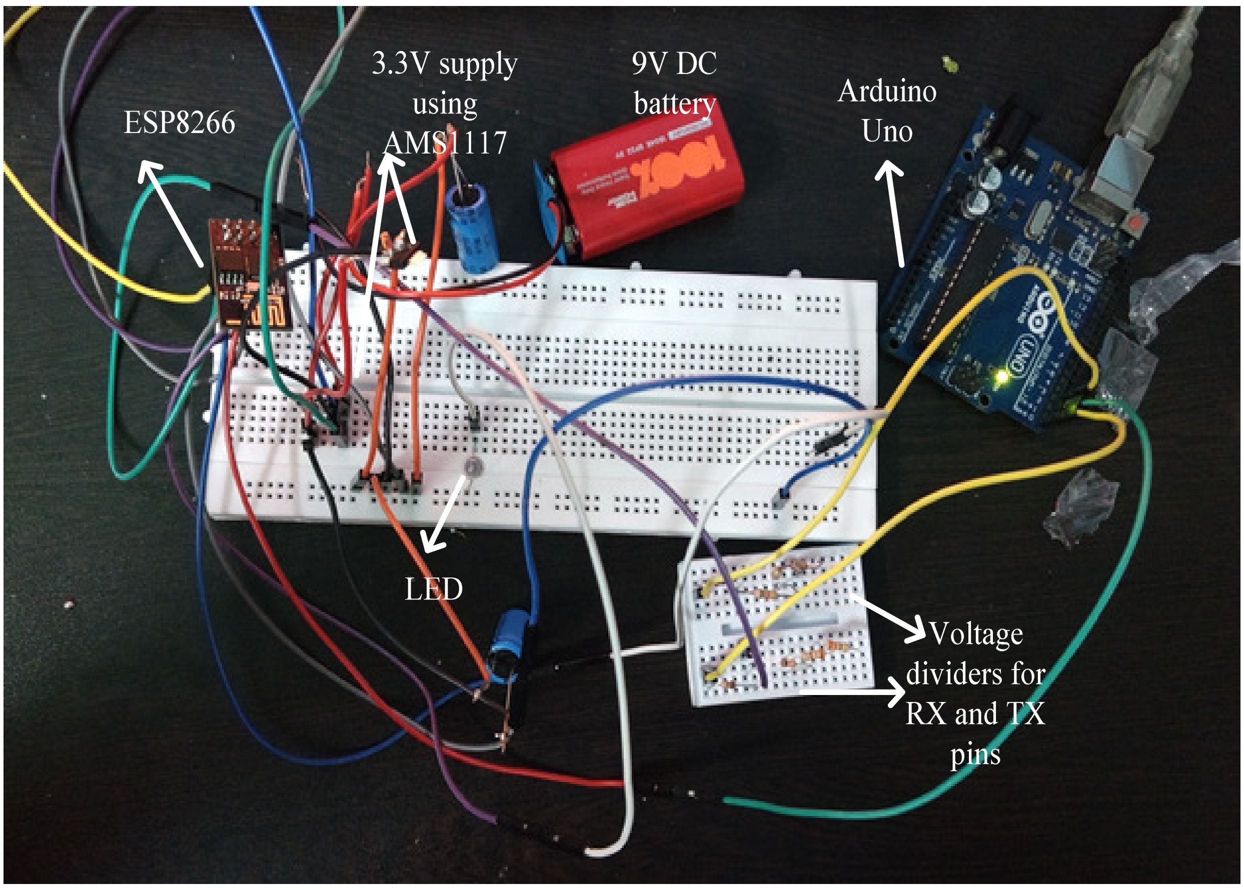

Figure-7: Arduino sensor node test circuit.

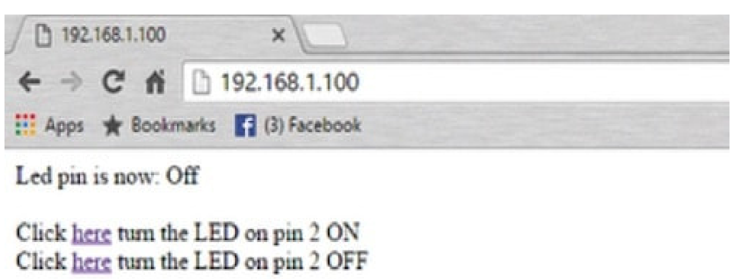

Figure-8: Screenshot of the developed internet interface for the Arduino sensor node test circuit.

Results

A complete IoT based sensing system is proposed for Substation automation application in Smart Grid environment. Various parts of the system are discussed in detail along with their possibility of application alongside the present substation automation systems. An overall implementation of the system including network topologies, wireless communication networks and secure communication with other parts of the power grid is also discussed. The MQTT protocol suggested in the proposed system is relevant to the substation environment and provides a reliable and secure way to communicate sensor data to a large audience. The system design is cost effective and easy to implement and configure. It provides a new approach to monitor, store, visualize and communicate the sensor data using IoT in the substation environment. The proposed system is currently under implementation and an Arduino sensor node prototype has been tested as a part of it. Remaining implementation of the work is expected to be completed soon and presented in further research.

Conclusion

IoT is expected to become a major enabling technology in the Smart Grid environment and substation automation is not expected to remain untouched. The present work is one of the many possibilities to integrate IoT in substation automation. It presents an Open Source based system which provides a versatile platform for development of unique application that can be used in the Smart grid environment. For future, the given system can be attempted to be integrated with other device in substation automation systems such as PLC (Programmable Logic Controller) and DCS to for increased robustness in the system. An extended system to control the substation equipment in real time using remote access is also an exciting possibility.

References

1. Zanella Andrea, Bui Nicola, Castellani Angelo, Vangelista Lorenzo and Zorzi Michele (2014). Internet of Things for Smart Cities. *IEEE Internet of Things Journal*, 1(1), 22-32.

2. Bush S., Goel F. and Simard S. (2013). IEEE Vision for Smart Grid Communications: 2030 and Beyond Roadmap. *IEEE Vision for Smart Grid Communications*: 2030 and Beyond Roadmap, 1-19.

3. Molderink A., Bakker V., Bosman M.G.C., Hurink J.L. and Smit G.J.M (2010). Management and Control of Domestic Smart Grid Technology. *IEEE Transactions on Smart Grid*, 1(2), 109-119.

4. Ingram M. and Ehlers R. (2007). Toward effective substation automation. *IEEE Power and Energy Magazine*, 5(3), 67-73.

5. Dispersed Generation Photovoltaics (2007). IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems. IEEE Std 1547.3-2007, 1-160.

6. Nielsen Jimmy J., Ganem Hervé, Jorguseski Ljupco, Alic Kemal, Smolnikar Miha, Zhu Ziming, Nuno Pratas K., Golinski Michal, Zhang Haibin, Kuhar Urban, Fan Zhong and Svigelj Ales (2017). Secure Real-Time Monitoring and Management of Smart Distribution Grid using Shared Cellular Networks. *IEEE Wireless Communications,* 24(2), 10-17.

7. IEEE Standard for Exchanging Information Between Networks Implementing IEC 61850 and IEEE Std 1815(TM) [Distributed Network Protocol (DNP3)] (2016). IEEE Std 1815.1-2015 (Incorporates IEEE Std 1815.1-2015/Cor 1-2016), 1-358.

8. Kelly S.D.T., Suryadevara N.K. and Mukhopadhyay S.C. (2013). Towards the Implementation of IoT for Environmental Condition Monitoring in Homes. *IEEE Sensors Journal*, 13(10), 3846-3853.

9. Sajid A., Abbas H. and Saleem K. (2016). Cloud-Assisted IoT-Based SCADA Systems Security: A Review of the State of the Art and Future Challenges. *IEEE Access*, 4, 1375-1384.

10. Papageorgas P., Piromalis D., Iliopoulou T., Agavanakis K., Barbarosou M., Prekas K. and Antonakoglou K. (2014). Wireless Sensor Networking architecture of Polytropon: An open source scalable platform for the smart grid. The International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES14, Energy Procedia, 50, 270-276.

11. Ahmim A., Le T., Ososanya E. and Haghani S. (2016). Design and implementation of a home automation system for smart grid applications. 2016 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, 538-539.

12. Hunkeler U., Truong H.L. and Stanford-Clark A. (2008). MQTT-S—A publish/subscribe protocol for Wireless Sensor Networks. 2008 3rd Int. Conf. Commun. Syst. Softw, 791-798.

13. Szabo Robert and Farkas K. (2013). Publish/Subscribe Communication for Crowd-sourcing Based Smart City Applications. ICTIC - Proceedings in Conference of Informatics and Management Sciences, no. 1, 314-318.

14. Arduino (2017). Anci CRT Monitor Revived Using An Arduino UNO[Online]. Available: http://www.arduino.cc/

15. MQTT (2017). Message queue telemetry transport. [Online]. Available: http://mqtt.org/