An IoT-Based Data Collection Platform for Situational Awareness-Centric Microgrids

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***Abstract*—This paper presents a data collection architecture for situational awareness (SA)-centric microgrids. A prototype has been developed which can provide enormous data collection capabilities from smart meters, in order to realise an adequate SA level in microgrids. A communication framework based on the publish-subscribe model is also proposed and implemented for the communication layer of the SA using the message queuing telemetry transport (MQTT) protocol over two different physical (PHY) layers (i.e., WiFi and GPRS). An Internet of things (IoT) platform (i.e., Thingsboard) is used for the SA visualisation with a customised dashboard. It is shown by using the developed system, an adequate level of SA can be achieved with a minimum installation and hardware cost. Moreover, the Modbus protocol over the RS-485 is applied for the smart meter communication.**

***Index Terms*—Distributed computing and measurement, MQTT, publish-subscribe model, situational awareness, smart grid.**

I. Introduction

Smart grid is designed for the next-generation power systems, transforming traditional power generation, transmission, and distribution systems to a platform where producers and consumers can provide data to optimise the cost and energy, as well as increasing the reliability of the smart grid [1], [2]. The new structure is advancing towards the interconnected autonomous microgrids. Furthermore, along with the progressive advantages, such division and separation of concerns would introduce a number of challenges in coordination of players, i.e., users, utility companies, and automatic control system [3]–[5]. In order to address the challenges, this complex grid has to extensively use the latest communication technologies such as situational awareness (SA) [6]–[8]. Blackouts in the grid can be detected using the SA by sending the critical information to the people involved in its operation [4]. To include numerous similar incidents, organizations from different domains have developed advanced information systems to support the realisation of the adequate level of SA [9]–[12].

According to the Endsley's definition, SA consists of three main layers of operation; i.e., perception, comprehension, and projection [13]. From the data collection standpoint, the most important layer is the perception, owing to the fact the grid communication technologies determine the quality and volume of the real-time data. The limitations in the data perception in the grid, considerably affect the SA adequacy [14], [15]. This limitation gets even worse when the machine and deep learning techniques are applied to achieve the SA in operator stations, as these techniques are heavily data-driven, and a large volume of data should be collected from the smart grid [16].

Realisation of the adequate SA based on the high data volume exchange, necessitates the bandwidth of grid communication technologies to be effectively employed to overcome the limitations regarding the accuracy in the data collection. Several communication models are reported to control the data collection and bandwidth usage. The request-response model is designed for the bidirectional master-slave data collection [17]; a number of models are proposed for the industrial IoT and large-scale networks of objects [18]. Furthermore, the publish-subscribe communication model is suggested for the big data collection, which is the primary model in the MQTT [19].

The SA architecture for microgrids is studied in this work, where different monitoring areas of adequate SA in microgrids are discussed. The MQTT protocol is proposed for the data collection using the SA architecture, and a device is developed based on this protocol. To extend the application domains of the proposed device, it has been designed as a multiprotocol one, in order to support the LoRa, GPRS, and WiFi protocols. The Thingsboard web-based dashboard is also used as the SA server for the data visualization and microgrid management.

The rest of the investigation is organised as follows. Section II describes the SA in smart grid. In Section III, the proposed MQTT protocol is presented and its unique features are discussed. The developed hardware and software are described in Section IV where it is shown by using the device, an adequate SA for microgrids is achieved with a minimum installation and hardware cost. The paper is concluded in Section V.

II. Situational Awareness-Centric Microgrids

Traditionally, the SCADA systems in microgrids monitor the basic variables and states to control both the power quality and demand response. One of the primary advantages of the microgrids is the enhanced grid monitoring, from the demand response and power quality to the smart user behaviour. This makes the smart grid not a sole entity providing services to consumers, but also a collection of different systems and technologies cooperating together to bring the highest reliability at the lowest cost with the participation of power consumers.

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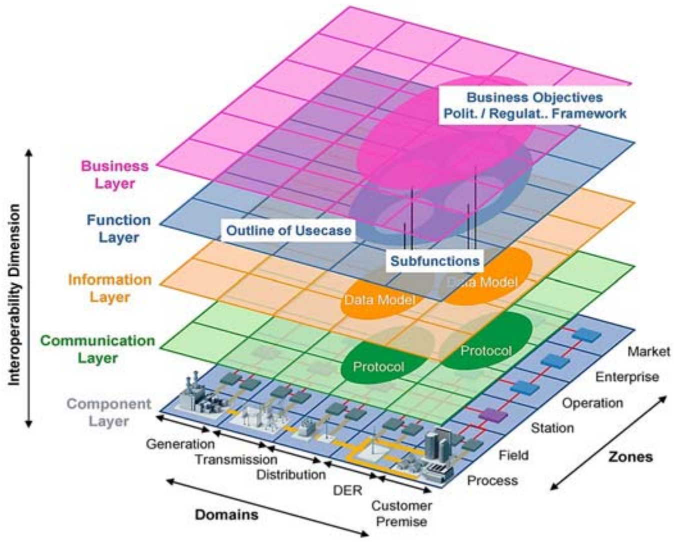

Fig. 1. Multilayer smart grid with different situational awareness domains.

A smart grid is a multilayer, distributed, and multidomain system in which different types of operations are taking place in tandem. A close coordination should occur among all the players with different goals. Naturally, SA is designed for such a smart grid should be multilayered where in each layer, a team SA handles the versatile tasks, such as the load forecasting, equipment health monitoring, power quality monitoring, cybersecurity, and unit commitment. This multilayered grid with the SA architecture is shown in Fig. 1.

New functionalities of the modern grid comes with the cost of security risks of open subnetworks connected to the Internet. If in the past, industrial systems were considered secure, due to the use of proprietary controls and limited connectivity, smart grid increases the number and exposure of SCADA systems, and consequently sustaining the security issues in the network. Implementation of the adequate SA for micorgrids still needs to be developed further in a number of crucial areas, including:

- *Communication infrastructure monitoring*
  Faulty operation of the communication devices can lead to a verity of unknown issues bringing the entire system down. Hence, the efficient monitoring of the operation of the switches and advanced metering infrastructure (AMI) gateways would guarantee a reliable system.
- *Equipment health monitoring*
  Health monitoring of the equipment especially in the distribution systems, is possible through the IoT platforms. Every equipment can be monitored from different control centres across the multilayered grid. The SA system can use health monitoring data in order to make pre-emptive decisions. For instance, number of failures in protection devices in a specific area of smart grid, can pinpoint the design problems in that specific area. This can be used for the prioritised maintenance.
- *Power generation and consumption*
  The unit commitment in a smart grid is different from the one in a traditional grid, in which the power generation programming are merely based on the behaviour of the two players (i.e., power plant constrains, as well as load dynamics). Each player makes decisions based on different factors, such as weather and time. In a smart grid, number of players are continuously increasing due to different structure in the decision making. Distribution companies seek high income, where the consumers need cheap energy. The adequate SA can accommodate this multiplayer decision-making scenarios, in order to improve the power system operation and planning.
- *Microgrids connection status*
  Different logics operate behind the microgrid operation which decides that in which situations the micorgrids should operate in an islanded mode or in a connected mode. Awareness of when and why a microgrid gets disconnected from the main grid makes the unit commitment and tertiary control cost effective and resilient to the faulty and abnormal situations.
- *Cybersecurity*
  One of the most important factors in the adequate SA framework is the cyber SA. The appropriate analysis of the network traffic, as well as the distributed intrusion detection systems (DIDS) can be employed to increase the security of the overall SA-centric system.

The presented topics by no means are the exhaustive list of the research topics in an adequate SA system, but it covers the most important issues which can be used as a starting point.

III. Data Collection Architecture

One of the main characteristics of the advanced IoT devices is the machine-to-machine (M2M) communications, which is presented in this work as a communication between multiple sensor devices and a single data collection device. The sensor devices are mostly installed in an isolated area, e.g., a rural area where connection to the Internet is limited or realised over a weak connection. In such an environment, a high number of lost packages would result in a poor reliability. There are several protocols proposed for the M2M/IoT communications, in order to improve the reliability in such constrained environments. The widely employed ones include the MQTT protocol, and the constrained application protocol (CoAP).

MQTT is an M2M/IoT protocol; i.e., top of TCP/IP stack; designed as a lightweight broker-based publish-subscribe model with small code footprints (e.g., 8-bit and 32 KB flash size microcontrollers) and a low bandwidth and power usage. The protocol is suitable for costly connections with a low-latency, variable availability, and quality of service (QoS), in which a broker (i.e., a server) forwards messages from smart meters to monitoring devices in an operator room. This protocol has been applied in a variety of embedded systems. For instance, hospitals use MQTT to communicate with pacemakers, and oil and gas sectors also use it for pipeline monitoring purposes. Facebook Messenger employs this protocol for the messaging services. Fig. 2 shows the layers of the MQTT protocol based on the publish-subscribe model over the TCP/IP connection.

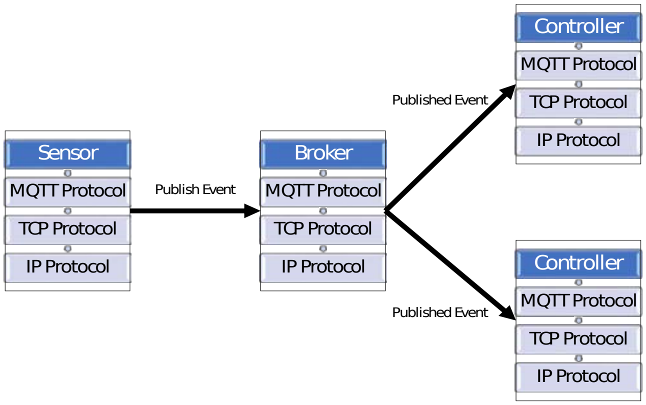

Fig. 2. Block diagram of the constituent layers of the MQTT protocol based on the publish-subscribe communication model for the IoT applications.

Fig. 3. Developed IoT-centric hardware prototype with the connected smart meter over the RS-485 protocol.

MQTT is a topic-based publish-subscribe protocol, and the topics are predetermined string parameters which can be set statically or dynamically during the operation. In this model, each smart meter publishes data with its own corresponding topic to the brokers. The brokers distribute this data to different SA servers, subscribing to that specific topic. In this way, the network traffic is substantially reduced due to the event-based nature of the data exchange. This makes the MQTT protocol an ideal candidate for the battery-based data collection devices.

IV. Developed Prototype for Situational Awareness-Centric Microgrids

The developed IoT node consists of three protocols that can be used in different situations. GPRS is a cellular one that has the coverage in urban and rural propagation areas. The publish-subscribe model solves the problem of GPRS low data rate since the need for a higher data rate diminishes significantly. The IEEE 802.11 protocol is a local area protocol with higher data rate and energy consumption but short distance coverage. The ESP-12E network module is used as the main module of the prototype. Furthermore, LoRa is a long-range low-energy protocol introduced specifically for the IoT applications and services that the developed hardware prototype, supports. The specifications of the device is shown in Table I. Fig. 3 presents the prototype that is connected to a smart meter.

TABLE I
Specifications of the Developed Hardware Prototype.

Microcontroller	2 × Atmega328P-AU
Flash Memory Size	2 × 32 KB
Communication	GPRS WiFi LoRa RS485 RS232
Digital I/O	3 × Output Relays 3 × Digital I/Os
Analogue Input	3 × Analogue Inputs - 0 to 10 V
Battery Capacity	3000 mAh

Fig. 4. Developed web-based dashboard using the Thingsboard IoT platform.

Since microgrids will be installed in private urban or rural areas, the monitoring software should be accessible easily by the operators, and also a well-designed human machine interface (HMI) is essential in order to achieve the adequate SA for microgrid operators. In this regard, the web-based dashboards are suitable for this purpose, as they can be remotely accessed. In this work, the Thingsboard open-source software is used as the operator dashboard. Thingsboard is a web-based dashboard designer written in Java which provides different widgets to visualise the values received from the developed nodes. Fig. 4 shows the dashboard interface developed using the HTML5, CSS, and Javascript programming languages.

The MQTT protocol necessitates a broker to be employed for the data collection and distribution. There are two options for the brokers. The Mosquitto MQTT broker is a software specifically designed for the message queuing and distribution. Thingsboard provides the MQTT broker in order to have a total solution. In this work, the Thingsboard MQTT broker is used. The data collection architecture for the situational awareness-centric microgrid platform based on the IoT protocols is shown

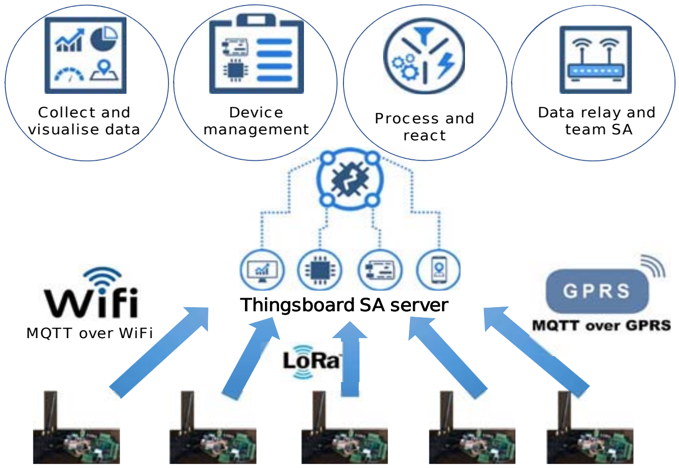

Fig. 5. Situational awareness-centric platform based on the IoT protocols.

in Fig. 5. By using the mentioned protocols and devices, the cost of monitoring of smart grid is greatly reduced for realising the adequate SA. The upper layers in SA usually need different types of data in order to analyse the current state of microgrid. The developed hardware device is comparably more affordable than the existing monitoring devices which makes it an ideal choice for big data collection in smart grid.

The software stack developed for this device, fully supports the Arduino integrated development environment (IDE). This results in the software customisation with a low-cost. Many libraries are developed for the Arduino that can be employed seamlessly in this device. The battery life is also extended due to the event-based communication using MQTT. Hence, lower rating batteries can be used which leads to cost reduction.

V. Conclusion

An adequate situational awareness (SA)-centric platform has been thoroughly implemented in this work to increase the overall reliability of the microgrids. A device is developed which extends the data collection capabilities of the adequate SA system to collect data from smart meters. Publish-subscribe model is proposed for the SA architecture using the MQTT protocol over WiFi, GPRS, and LoRa communication protocols. The Thingsboard IoT is employed for the SA visualisation software with a customised dashboard. It is shown by taking advantage of the new device and the proposed publish-subscribe model, adequate SA can be implemented with minimum installation and hardware cost. Using the proposed IoT system, microgrid operators are able to predict all the unknown incidents in the microgrid by collecting detailed information from consumers' smart meters, and other operators in the grid. All the important areas for the realisation of the SA-centric micorgrids have been highlighted, which need to be addressed in the future works.

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