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Implementation of Machine-to-Machine Solutions Using MQTT Protocol in Internet of Things (IoT) Environment to Improve Automation Process for Electrical Distribution Substations in Colombia

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Abstract

In order to incorporate smart elements into distribution networks at ITELCA laboratories in Bogotá-Colombia, a Machine-to-Machine-based solution has been developed. This solution aids in the process of low-cost electrical fault location, which contributes to improving quality of service, particularly by shortening interruption time spans in mid-voltage grids. The implementation makes use of MQTT protocol with an intensive use of Internet of things (IoT) environment which guarantees the following properties within the automation process: Advanced reports and statistics, remote command execution on one or more units (groups of units), detailed monitoring of remote units and custom alarm mechanism and firmware upgrade on one or more units (groups of units). This kind of implementation is the first one in Colombia and it is able to automatically recover from an N-1 fault.

Keywords

Machine to Machine, Quality of Service, Distribution Grids, MQTT Protocol, Internet of Things (IoT) Environment, Electrical Energy

1. Introduction

Demographic trends and industrial growth have prompted an increase in electrical energy demand and also have promoted the use of new technologies, which is accompanied by increased complexity in the type of solutions that are to be implemented in high-power electrical systems. In most cases, companies have made particular efforts trying to adopt standards and apply better practices. However, the increase in energy demand together with the particular financial and social conditions of customers have forced companies to operate under safety-limit

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conditions and also to reduce generation margins [1].

When facing various undesired situations (e.g. machines failing to start, transmission problems with complete boiler-pump-motor subsystems) that lead to deficient energy production, it is absolutely necessary to take actions that allow identifying the point at which failure is occurring, thus guaranteeing better supply quality. Based on this premise and also in an attempt to assist failure-location processes in electrical systems, implementation of smart devices within distribution grids was proposed (supported by Itelca S.A.S) in order to develop a complete machine-to-machine solution for failure detection that also incorporates the latest available technology. This technology makes use of MQTT protocol in an Internet of things environment which it is able to guarantee an immediate recovery from an N-1 fault. It helps to short interruption time spans in mid-voltage grids which improve quality of service for residential, commercial and industrial customers.

2. Internet Protocols for the Smart Grid

One of the reasons why a machine to machine (M2M) implementation in an Internet of things (IoT) environment is too difficult relies on the large number of communication protocols for the different devices within the automation process [2]. According to this, it is proposed an open source implementation for protocols well adopted in machine to machine solutions. One of these protocols is MQTT (Message Queuing Telemetry Transport which is a protocol designed to connect physical devices with applications used in web development making it the best option as connectivity protocol for IoT and M2M.

In **Table 1** a comparison between different protocols is shown. MQTT protocol clearly is recommended for automation in substations applications. In fact, CISCO and other partners are making efforts to develop a standardized version of the MQTT protocol.

3. Machine-to-Machine Solutions in Colombia

M2M technology is a whole concept that involves communication among machines, allowing process automation between mobile devices and machines (Mobile to Machine), and also between men and machines (Man to Machine). These machines range from very small electronic devices (e.g. communication/entertainment personal equipment) to measurement/control equipment (e.g. sensors and smart meter or actuators); and also from smart electronic labels, micro-processors embedded in household appliances, cars or offices, to personal computers or complex servers located at large data processing centers.

M2M assists communication between its own devices and information centers regardless of their location; this technology also facilitates communication with other types of devices and with people in various places through the use of personal communication devices instantly (in an organized fashion). Through M2M communication, it is possible to offer a wide variety of services in the fields of telemetry and tele-control (e.g. vehicle-to-vehicle communication, remote monitoring of public utility consumption), telemedicine and tele-assistance, security services and corporate/domestic remote-control applications. This represents the beginning of the so called Internet of Things.

Table 1. Comparison of different IoT protocols. Source: cisco.

Protocol	CoAP	XMPP	RESTful HTTP	MQTT
Transport	UDP	TCP	TCP	TCP
Messaging	Request/Response	Publish/Subscribe Request/Response	Request/Response	Publish/Subscribe Request/Response
2G, 3G, 4G Suitability (1000 s nodes)	Excellent	Excellent	Excellent	Excellent
LLN Suitability (1000 s nodes)	Excellent	Fair	Fair	Fair
Compute Resources	10 Ks RAM/Flash	10 Ks RAM/Flash	10 Ks RAM/Flash	10 Ks RAM/Flash
Success Storied	Utility Field Area Networks	Remote management of consumer white goods	Smart Energy Profile 2 (premise energy management/home services)	Extending enterprise messaging into loT applications

Together with the development of internet-based connectivity as well as the development of smart energy sensing and energy measurement devices, there have been significant advances in unconventional renewable energy sources, particularly regarding solar energy, electrical grid operation controllers and storage batteries. This will allow better energy management in the near future in every city through the use of Smart Grids, A smart Grid is basically a system that integrates electricity transport and distribution with information technology, allowing real-time communication between customers, distribution devices, transporters and generators by using particular devices intended to guarantee more efficient, sustainable energy consumption. Thus it is possible to facilitate operation for every party (customer, generator, transporter, etc.) within an electricity-exchange free market [3].

4. Design of a Machine-to-Machine Solution

The solution proposed herein was supported by the broad experience of ITELCA S.A.S. regarding the import and commercialization of products associated to telecommunications systems as well as the development of integrated ICT solutions. This Colombian company was founded in March 1987 and is currently certified by Bureau Veritas Quality International under standard ISO 9001 version 2008. The company participated in the proposal and construction of the following solution and provided an added value to the service supply as well as to the quality-of-service commitment to all its associated projects.

The system was implemented a using proprietary design developed in order to provide coverage to rural areas whose lightning rates per year are significant; thus the system provides failure alerts for low-consumption areas where traditional solutions that use equipment such as reclosers offer no financial competitiveness. The system consists of:

4.1. Direct Current Feeding Equipement

This equipment provides autonomous operation for customized periods of time according to the corresponding needs of each area. The equipment deals with rectification and conversion into adequate voltage levels.

4.2. Solar-Power Backup Resource

Companies involved in development and management of renewable energy sources, locally and internationally, have promoted the use of renewable energy that satisfies energy-supply needs and avoids massive emissions of CO_2 into the atmosphere (tons of CO_2). Such is the case of Enel Group, which is world-class leading company capable of providing up to 8700 MW (already installed) by gathering various types of sources such as eolic, solar, hydro-electric, geo-thermal y biomass; involving at least 740 operational plants in 16 countries throughout Europe and America [4].

In Colombia, the relative participation of alternative energy sources can be found in Alta Guajira, where EPM (Empresas Públicas de Medellín) installed the very first Colombian wind farm, called Jepirachí, consisting of 15 air-based generators that feed 19.5 mega-watts into the National Interconnected System. In regions such as Santanderes, the Eastern Plains and the Atlantic Coast, there are already various bio-mass-based generation projects. Potential solar-energy sources are to be explored in other areas like Magdalena, La Guajira, San Andrés y Providencia; and according to UPME, there is an estimate of energy generation obtained from oceans that may reach 30 GW, exploiting 3000 Km of coastal zones [5].

Following and supporting this global (and recently local) initiative, a backup solar source was implemented in order to guarantee permanent monitoring activity, even under extended-failure conditions, in failure indicators due to over-current in medium voltage circuits.

4.3. Geneko Router

GWR-HS high speed cellular router series "**Figure 1**" represents a group of industrial graded cellular routers specially designed for expansion of existing industrial networks, remote telemetry and data acquisition in harsh environments. These routers now feature new LCD display enabling user-fiendly monitoring and network control. There are several models with 1, 2 or 5 ethernet ports or one with ADSL2+ feature bundled with Wi-Fi. **Figure 1** shows a Geneko GWR-HS high speed cellular router series. Geneko and its partner in the router manufacturing Huawei make part of M2M alliance, the largest association for the machine to machine sector.

Figure 1. Geneko GWR-HS High speed cellular router series.

This router is a pure machine to machine connectivity solution. Easy to install, reliable and high performance router models from GWR-HS cellular router series introduce a completely new dimension into industrial networking area. Many useful features make GWR-HS cellular routers a perfect solution for wide variety of industrial applications [6]:

- Dual SIM card support increases the reliability of the router and provides a solution for those applications where failure of one mobile network must not result in system downtime. Automatic failover feature will detect the failure of primary connection and automatically switch to alternative connection. When the connectivity over primary connection is restored GWR industrial router will perform switchover to primary connection.
- Successfully tested in real world applications. It can be used to replace wired solutions using 4G cellular network. Without using heavy machinery for digging and bringing the cable to the site, the total project's cost is much lower when using a fast 4G network.
- The whole set of advanced WAN settings allow a user to specify desired parameters in order to meet the requirements of specific cellular network. GWR-HS routers proved themselves to be reliable and high performance devices in so many countries around the world. All advanced parameters included represent the result of detailed analysis of large number of different cellular networks. In few simple steps it is possible to optimize the performance of the industrial router on almost any cellular network.
- VPN (GRE, IPsec and OpenVPN) tunnel support provides powerful options for network expansion and secure data transfer over the cellular network.
- With Serial-to-IP feature it is possible to connect, control and perform data acquisition from almost any device with serial RS232 port. In addition to this feature, GWR-HS industrial cellular router series implements Modbus RTU-to-Modbus TCP functionality designed to support expansion of Modbus SCADA networks over the cellular networks.
- Easy to use web interface, extended CLI (Command Line Interface), detailed log, SMS control feature, partial and full configuration Export/Import and remote management and monitoring software provide wide range of management functionalities. All those features and tools empower a user with full control over GWR-HS industrial routers.

5. Conclusions

The system development presented herein allows electrical energy companies to increase their failure detection capacity with low-cost procedures, because the system can be repaired by itself and in an automatic way even when facing faults as N-1 type. It helps to maintain the service in difficult conditions shortening interruption

time spans. In Colombia a massive use in the electrical sector of M2M solutions in IoT environment has begun with more than 400 devices in real operation. This work is a pioneer in Colombian electrical sector paving the way to adopt new strategies of MQTT protocol applications in IoT environments. The field of research in MQTT protocols in IoT environments is the future of smart grids in the electrical sector worldwide.

In the long term, massive adoption of new concepts regarding energy supply assisted by Machine-to-machine solutions will continue, which should contribute to reducing potential problems associated to apparent lack of safety and reliability of electrical systems. This should also promote a more efficient use of energy resources, thus lowering overall cost and having a positive impact on international markets. Likewise, these new ideas suggest that energy production should rely on renewable sources as well as on efficient use of the generated energy, perhaps achieving significant reductions in Green House Effect gases and also prompting greater social acceptance.

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