Spectrum Management for Microgrid

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Abstract

Wireless communications technologies are increasingly utilized to support the Modern power grid operations. Wireless technologies present unique challenges, especially the vulnerability to intentional and unintentional RF signal interference, the need for allocated RF spectrum, and radio system interoperability issues. Because of these challenges, spectrum management becomes an important problem to address. The Utility Telecom Council stated that there is an RF spectrum crisis in the utility industry [1]. Specifically, the network and communications infrastructure in the Modern power grid provides the foundation for power grid information, control, and knowledge management. If RF systems are not highly reliable and secure, serious consequences can occur.

This paper summarizes the concept for spectrum management technology for the electric utility industry and its application to Microgrids. The paper contents are based on material from IEEE 802.22 and SCC41 (P1900.4) standards working groups for interoperable spectrum management in heterogeneous radio networks [2, 3]. Spectrum management technology is coupled with an emerging wireless spectrum sensing technology called Dynamic Spectrum Access (DSA). DSA technology enables a comprehensive solution to the spectrum management crisis. The solution can improve spectrum utilization efficiency, risk mitigation, and reliability of RF systems in Microgrids and the modern power grid.

1. BACKGROUND

A myriad of technologies such as Wi-Fi, WIMAX, ZigBee, 2G and 3G cellular, microwave, satellite, Land Mobile Radio (LMR), RFID and SCADA networks are currently used or planned in the Modern power grid. Currently, RF spectrum is being "managed" using FCC and NTIA static spectrum allocations. As early as 2001, a National Telecommunications and Information Administration (NTIA) report on spectrum use in the energy, water and rail industries summarized feedback received from utility companies across the country [4]. Recently, spectrum has been auctioned off for unlicensed use while other spectrum is assigned for licensed use and accessible only by devices that meet strict operational restrictions. These conditions contribute to artificial spectrum scarcity and suboptimal allocation of spectrum. In today's electric utility industry, product vendors supply an RF system solution for a specific operations function. However, the utility rarely examines the interference effects of unlicensed bands and users, weather effects, geographical, and foliage during operations.

Dynamic spectrum management due to spectrum scarcity and under utilization is a new concept to the utility industry. Specific examples of RF systems used by utilities are Advanced Metering Infrastructure (AMI) RF mesh networks, LMR work force networks, and microwave systems, which operate in the 2.4 GHz in unlicensed bands. To solve the basic problems in spectrum use domains, DSA and spectrum management methods have been addressed by the IEEE 802.22 WRAN, Draft v2.0 and SCC41 P1900.4TM working groups and standards have been published [2, 3]. The dynamic spectrum management solutions can result in improved spectrum utilization and efficiency and in increased reliability of Microgrids. The spectrum management system goals and approach, technology, and spectrum management processes are described in the paper.

There is a necessary underlying phase to determine the spectrum management requirements within the electric utility markets. These requirements are unique to each utility, however there exists a fundamental spectrum management framework that can be applied to all utility environments, whether they are large, medium, small, regulated, or public. The NIST Modern power grid Interoperability Roadmap project is a first step to investigate these requirements and appropriate use cases [5]. The NIST Roadmap v1.0 contains a section describing electromagnetic disturbances and interference as areas that need to be addressed. This paper presents the concepts and a starting point for those requirements and emerging solutions.

There are several benefits to a utility that deploys spectrum management technology. The overall RF system situational awareness is improved. This results in better real-time field crew operations and utilization. Risk mitigation for outage management, metering, SCADA information, demand response, and security is greatly improved. The ability to understand frequency interference sources and avoid them can result in increased reliability of the RF communications network.

For reference and context purposes, General MicroGrids defines a Microgrid in the modern power grid as follows:

A Microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources capable of operating independent of the larger grid. Microgrid components include; distributed energy resources (including demand management, storage, and generation), control and management, secure network and communications infrastructure, and assured information management. When renewable energy resources are included, they usually are of the form of wind power, solar, hydro, geothermal, waste-to-energy, and combined heat and power systems. Microgrids perform dynamic control over energy sources enabling autonomous and automatic, self healing operations. During normal or peak loading or at times of power grid failure the Microgrid can operate independently from the larger grid and isolate its generation nodes and loads from the disturbance without affecting the larger grid's integrity. Independent Microgrid operation can offer higher reliability and cost efficiency than that provided by traditional grid control. The Microgrid is both an energy market consumer and provider of electrical power. Microgrids interoperate with existing power systems, information systems, and network infrastructure. The Microgrid may take the several forms, such as a utility metropolitan area, a shopping center, industrial park, college campus or a small energy efficient community.

1. SPECTRUM MANAGEMENT GOALS

Spectrum interference and scarcity have traditionally been used as arguments for governmental and regulatory intervention. With the escalation of spectrum interference and unlicensed bands in utilities, spectrum management becomes a set of functions that needs to be closely examined. The key goals for spectrum management for Microgrids are:

1. Achieve spectrum utilization and efficiency in the geographical Microgrid region

2. Improve utility operational efficiency through spectrum situational awareness
3. Promote interoperability between utility radio systems and networks.

Ensuring effective use of the radio spectrum can be seen both from a technical and an economic viewpoint. While a technical approach to frequency management mainly focuses on maximizing the supply of radio frequencies, economic measures are used to ensure that the supply of radio frequencies maximizes the economic value of spectrum use. From a technical viewpoint, the objective is to optimize the physical use in terms of number of users and the amount of radio signals in a band. From an economic viewpoint, the objective is to give preference to the most valuable and critical applications. Allocation and assignment of the radio spectrum resources have traditionally been seen mainly as a technical issue and not an economic issue. The purpose of spectrum regulation is to avoid interference between users and to optimize the allocation of spectrum resources in order to provide access to everybody. Business processes that implement spectrum management solutions that are regulatory and policy compliant must also be put in place.

3.0 SPECTRUM MANAGEMENT APPROACH

In this section, the spectrum management approach is outlined for a utility that incorporates Microgrids. Spectrum management is based on three use cases developed by the P1900.4 committee [3]. Figure 1.0 describes the DSA and spectrum management function in context within a Utility Network that includes RF and static networks. Figure 1.0 shows network and spectrum management for a typical utility of the future. Utilizes incorporate multiple RF systems in their Microgrid environment. These include 3G/4G cellular systems and LMR radio networks that communicate with legacy radio units. The radios represent off-the-shelf products and interoperate only within their assigned frequency band. The utility hosts an AMI network whose legacy smart meters communicate only between themselves and their aggregators and headend. The utility may have a combination of WiFi and WiMAX backhaul networks. Finally, the utility has an Intranet that is mostly fixed infrastructure for communications in the Microgrid and backend office applications. Future wireless and fixed network nodes in the utility Intranet and backhaul networks may have DSA-enabled nodes that act as spectrum measurement nodes and in collaboration form the basis for spectrum situational awareness. These nodes provide the spectrum information used for the utility's spectrum management system. Eventually, the RF legacy equipment may include DSA-enabled radio units. How are the spectrum measurements made in this environment and how is the spectrum managed?

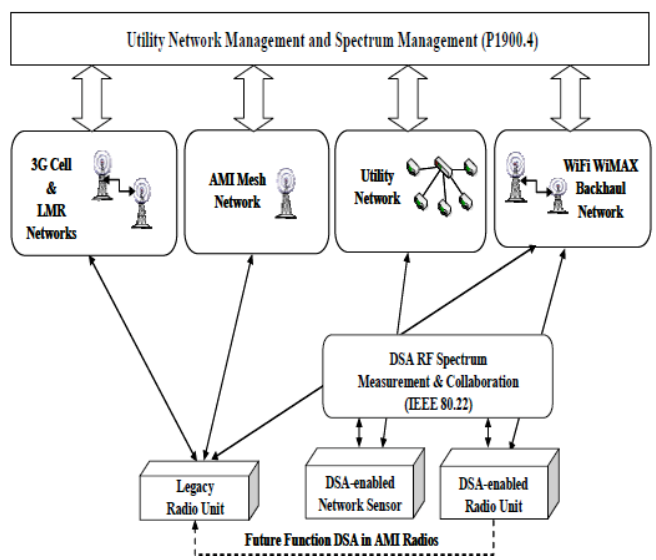

Figure 1.0 Spectrum management and DSA in a Utility Network

The three use cases that govern the operations for spectrum management and spectrum situational awareness are summarized here. They include the following functions:

a. Dynamic spectrum access – describes how the frequency bands assigned to RF networks are used. A frequency band can be shared by several RF networks. Distributed spectrum managers analyze the information from the DSA algorithms and dynamically make spectrum access decisions according to regulations and policies. Dynamic spectrum access may be done with or without negotiation.

b. Dynamic spectrum assignment – describes how an operator spectrum manager generates spectrum assignment policies that enforce regulations, policies, and tacit operation. The operator spectrum managers provide spectrum assignment policies to the distributed spectrum managers that coordinate with other RF networks.

c. Distributed radio resource usage optimization – describes how the P1900.4 methods can be used with legacy RF networks to make better use of the spectrum. This use case assumes the radio nodes have multiple channels so one channel is accessed as a control channel for frequency changes on the other channels.

These use cases are further described in the IEEE P1900.4 standard document [3]. Representative UML 2.0 use case examples that show entity and actor relationships are also presented by the authors [6]. The spectrum management functional and operational requirements are summarized in the following paragraphs.

3.1 Frequency measurement and planning are the first steps

Frequency measurements are integrated with network topology, node geo-location information, weather information, and mission planning. The traditional methods for spectrum measurements are to use a spectrum analyzer on a mobile unit and take field measurements for signal strength and interference sources. The new methods utilize a distributed spectrum measurement algorithm distributed among the utility geographical region. Analysis tools produce an optimal frequency plan with minimal interference across the network so that all network nodes experience a self maximized Signal-to-Noise Ratio (SNR). The frequency plan is optimized regionally so that the whole network has optimal performance among several parameters and constraints. The measurement functions are defined by the IEEE 802.22 Wireless Regional Area Network (WRAN) draft specification, v2.0 [2]. The distributed spectrum management in the P1900.4TM standard [3].

Tactical pre-planning is performed by automated adaptation to regional, local, and tactical policy and regulations. When performing spectrum management, accurate planning requires consideration of several performance degradation factors. Co-channel, adjacent channel, co-site interference, inter-modulation products, and frequency reuse constraints must be part of the regional analysis to enable successful frequency planning.

Spectrum measurement techniques rely on an intelligent RF front-end wideband RF receiver (or sensor node) that performs a real-time spectrum sensing function. The nodes are shown in Figure 1.0 as network sensors in a fixed network node (IP addressed) and as DSA-enabled radio units in a mobile or fixed network node. The spectrum measurement function is implemented in a Dynamic Spectrum Access (DSA) engine (DSA-enabled radio and sensor units in Figure 1.0 that determines the spectral “white space” and “gray space” available to avoid interference and allocate channels to increase spectrum utilization [2, 7].

a. Spectrum sensing function (SSF) – implements various classes of spectrum sensing algorithms and outputs signal type, signal presence, detection confidence, and field strength estimate. These outputs are sent to the spectrum management function.

b. Spectrum management function (SMF) – implements operations to 1) maintain spectrum availability information, 2) channel classification and selection, 3) association control, 4) channel management, 5) interfaces to the SSF and geolocation function (GLF), and 6) self-coexistence with RF networks.

c. Geo-location function (GLF) – implements the processes of acquiring the necessary location data, determining latitude and longitude, and producing the geo-spatial string information to the SMF.

These functions work (together with a security sub-layer function) to manage the frequency use of the network node when there is interference and jamming sources. Overall spectrum management incorporates frequency use policy and regulations at the utility level to enforce compliant operation of the RF network and its frequency use with FCC, FERC, and NERC regulations and policy.

The ability to combine distributed DSA-enabled node information produces a spectral map over a Microgrid geographical area. The historical data is stored and used by the optimization algorithms to predict link failure and predict the next best frequency to use for any given node in real time. Historically, the DSA-enabled nodes have been mobile, however in the utility scenario the nodes may also be part of the static infrastructure.

A communication system must operate in a continuously varying RF environment that depends on multiple parameters that are inter-related and non-linearly coupled. The communication system must adapt to the varying RF conditions. Optimization methods are required for sort recurring design patterns in the RF environment. Genetic algorithms (GA) are one method that be used to implement these adaptive processes and solve the optimization of RF parameters for a wireless network or set of wireless networks. A fitness measure is derived that provides a figure of merit for the performance of the GA algorithms in relation to the overall RF system performance. Additionally, a chromosome structure is derived which consists of “RF genes”. Each gene is a binary string representing an aspect or parameter of the RF environment. Finally the GA algorithm determines a set of RF parameters (frequency allocation and optimization are an example of the RF parameters) for optimal radio communications in the varying RF environment. The optimal frequency allocation ensures the overall minimal interference across the network and also maximizes data throughput and network performance. The design ensures the convergence is at global optimization not localized optimization. There are several assignment algorithms that can be used to achieve an optimal frequency allocation. The intention is to achieve a situation where the desired signal exceeds a defined margin with respect to interfering signals. Mitigation of interference is usually addressed by a combination of frequency offset and spatial separation.

3.2 Frequency Assignment Algorithms

The general approach to frequency assignment is to generate an initial viable assignment derived from a rapid sequential search and then use optimization techniques to further improve the solution. As with most optimization problems, there are a variety of constraints. For frequency assignment problems, the constraints describe the influence of potential co-channel and adjacent channel interference. Their total effect on the overall frequency assignment is assessed in terms of a cost parameter. The cost parameter reflects the total degradation of received signal quality within the frequency plan due to all the unwanted interference. The frequency assignment and deconfliction algorithms provide metrics which indicate the 'goodness' of the existing and new assignments. This is a key parameter in determining congestion points within the radio networks. Frequency assignment algorithms are versatile and can generate assignments for a variety of different systems.

3.3 Interoperability with legacy radio networks

Interoperability with a utility occurs at the network and basic connectivity levels within the GridWise Architecture Council (GWAC) document on the GridWise Interoperability Context-Setting Framework, v1.1 [8]. Interoperability with legacy radio networks is a key benefit when spectrum management is applied to an electric utility industry. Since the RF network solutions do not interoperate in utility operations, the spectrum management functions allow spectrum overlap and utilization at the management level. The spectrum management standards enable multichannel radio units to operate in different frequency bands. This allows assignment of one frequency channel as a management and control plane network while assigning another channel as a data network within the same radio unit. Since the radios are made by different manufacturers they normally do not have the same message formats for applications. A messaging gatewaying device is required at the spectrum management level to achieve interoperability between legacy RF networks at the Network layer. Spectrum management and frequency assignment enable the Physical and Media Access Control layers of the radio units to communicate through different frequencies and perform message translation in the gateway devices. The cornerstone of the interoperability is a common information model in the spectrum management functions.

4.0 Summary

The paper summarizes spectrum management concepts in the context of a utility environment that may have multiple RF systems deployed in their daily operations. The paper presents the current state of spectrum utilization and management as described by the FCC and IEEE standardization efforts. The policy and technology challenges facing the electric power utility have been conveyed from the UTC, DHS, NERC, and FERC. General MicroGrids believes there is a critical sense of urgency to address spectrum management issues and to system architect a MicroGrid design that encompasses spectrum management functionality. We believe there are measurable steps to apply, measure, and demonstrate the benefits and performance advantages in spectrum management and DSA technology for MicroGrids. With spectrum management, there will be reduced interference levels, SNR ratios will be improved, and channel utilization and spectrum utilization is achieved. Risk mitigation processes are improved due to availability of real-time spectrum utilization information and situational awareness. The benefits to RF system security and vulnerability is the topic of another paper that is addressed by NIST.

General MicroGrids believes that our system of systems and spectrum management subject matter experts represent a unique set of expertise and experiences that can benefit the electric power industry and provide a secure, lower cost, and more reliable MicroGrid RF environment operation.

Spectrum management is built into our Microgrid architecture processes.

For additional information, please contact the authors or visit, www.generalmicrogrids.com.

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