Pacific Gas and Electric Company

EPIC Final Report

Program	***Electric Program Investment Charge (EPIC)***
Project	***EPIC 2.28 – Smart Grid Communications Path Monitoring***
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Table of Acronyms (Alphabetized)

AMI	Advanced Metering Infrastructure
ANSI	American National Standards Institute
AP	Access Point
API	Access Point Interface
CVWS	Cloud Vendor Web Services
CC&B	Customer Care and Billing
CEC	California Energy Commission
CPUC	California Public Utilities Commission
EPIC	Electric Program Investment Charge
ESFT	Enterprise Secure File Transfer
ID	Identification
IP	Internet Protocol
IPSEC	Internet Protocol Security
KPI	Key Performance Indicator
LAN	Local Area Network
NAN	Neighborhood Area Network
PG&E	Pacific Gas and Electric Company
Ping	A utility used to test the reachability of a host on an Internet Protocol (IP) network
RF	Radio Frequency
RFI	Radio Frequency Interference
RSSI	Received Signal Strength Indicator
SA	Spectrum Analyzer
SMOC	Smart Meter Operations Center
TD&D	Technology Demonstration & Deployment
UL/DL	Uplink (UL)/downlink (DL) modulation
VPN	Virtual Private Network

1 Executive Summary

Pacific Gas and Electric (PG&E) Electric Program Investment Charge (EPIC) Project 2.28 Smart Grid Communications Path Monitoring was intended to demonstrate how an algorithm based approach could potentially continuously monitor, analyze/diagnose and identify radio frequency interference (RFI) that impacts the 400 MHz, 900 MHz and future 2.4 GHz AMI networks as well as develop an end-to-end process from monitoring-to-mitigation of such interference. PG&E expects there will be growing utilization of the frequency band leveraged by our AMI network as third parties continue to leverage that same unlicensed frequency band (900 MHz and 2.4 GHz) or licensed band (400 MHz) for their communications needs. This has the potential to create a situation where the increased data traffic will pose more data interferences. If the project had successfully been able to create an algorithm for detecting potential RFI affected areas as part of this demonstration, this would have positioned PG&E to be able to better proactively monitor communication paths, analyze radio frequency data, identify RFI, and manage the RFI to ensure reliability of smart grid networks.

1.1 Problem

Today, PG&E does not have technology to continuously monitor, analyze/diagnose and identify RFI that may impact the 400 MHz, 900 MHz, and 2.4 GHz AMI networks. This is a key risk and obstacle as network utilization grows and the need for monitoring communication paths and identifying radio communication interferences becomes more time and cost pressuring. For example, transmissions from other entities can overpower or interfere with PG&E's AMI meter transmission, resulting in packet damage or loss, which causes the metering devices to 'retry' the transmission. Sometimes the device may have to 'retry' several times. If the transmissions do not succeed, the billing systems have to estimate portions of the bill. If there is limited historical data available, the billing operations team may have to estimate the bill manually. This estimation would become more challenging if the level of interference and thus the level of data loss were to increase.

PG&E's current process for identifying RFI is reactive and resolutions will be sought after RF interferences arise and are identified. For example, network data that could not be collected as a result of interference from a third party impacting the AMI network might only be identified by missing read data and subsequent root cause analysis with a field technician's investigation using spectrum analyzers. Upon discovery, the field technician would initiate the resolution process and contact the 3rd party who might have caused the interference issues. Because of the time it requires PG&E to acknowledge that there is an RFI problem, the time required to identify the source of the RFI, the time required to mitigate the issue, and the labor costs associated with this process, the process will not be an ideal long term solution if RFI issues become more frequent in the AMI systems with the growth of 3rd party network connected devices.

1.2 Major Tasks

The project included the following major tasks. Each task was designed to be sequential and build on the previous work of the tasks before it:

1. Leverage spectrum analyzers to establish a sample and potentially network wide baseline of RFI
2. Develop an algorithm and application to proactively identify potential RFI affected areas
3. Mobilize probes to identify and confirm RFI sources, which verifies that the demonstration application is working as intended

4. Develop an end-to-end process from monitoring to mitigation of interference leveraging the algorithm created. As appropriate, take actions and next steps in accordance with Federal Communications Commission (FCC) rules and guidelines.

1.3 Key Accomplishment/Progress

The following summarize some of the key accomplishments of the project over its duration:

- Activated spectrum analyzers, collected a sample of RFI data at one instant in time, and determined that there is congestion on certain channels on the 900 MHz network.
- Developed a network configuration plan that would enable PG&E to gather relevant external data sources through a secure VPN tunnel onto PG&E's network.
- Identified minimum data points and sources of this data needed to identify the source of RFI and develop a proactive automated detection algorithm.
- Identified two methodologies for data discovery into the proposed RFI server.
- Conducted an initial assessment on the available spectrum analyzer and AMI data sets to understand deficiencies and barriers associated with using this data to identify RFI and developing algorithms to create an automated end-to-end tool.

1.4 Challenges

Unfortunately, PG&E was unable to obtain the necessary RFI data through our head-end network operations center or through our third party vendor who manages our head-end AMI application. This radio frequency data was found to be critical in developing and demonstrating the proposed new algorithm and associated application. The prerequisite for developing a good RFI algorithm relies on obtaining meaningful RF data from the actual AMI network itself, which will form the basis for comparison with the external RFI instrumentation which is used to measure external interference from third parties. Through PG&E's work on this demonstration, we discovered that neither the AMI network nor the head-end AMI application was able to provide the needed RF data operating parameters to formulate a starting point for building this interference criteria. A minimal amount of channel loading data for a small area in a San Francisco test area was obtained, however this data did not include critical data points and was not granular enough to be able to create the algorithm and application needed for proactive automated interference detection.

1.5 Conclusions

PG&E identified through a sample of RF data that there are potential channel congestion issues that can lead to RFI conflicts in our network. With increasing numbers and types of devices that will occupy the limited free RF bandwidth of AMI networks, it would be beneficial to understand and establish the local and system wide RF Baseline noise (interference) levels going forward in order to track the rate of growth in RFI and the levels of RFI impact in the AMI network operations. The work completed in this project could be leveraged in the development and/or use of future tools and in forming broader mitigation of AMI network RFI, once the needed data is available. The primary issue with the available data is that the needed AMI RF data elements are not available on a continuous basis, which is required and absolutely necessary for the development of the RFI system/application. It is clear that in order for an algorithm and application to be developed in the future, minimum information of data elements are required to evaluate RFI issues and their associated characteristics, and as a result utility partners should make RFI data access an important key requirement of their network vendors to effectively and appropriately monitor their networks. Through defining out the needed data, this limited trial has provided valuable information to help future capability developments in new AMI products by the vendors and operating entities alike.

2 Introduction

This report documents the EPIC 2.28 – Smart Grid Communication Path Monitoring project accomplishments, highlights key learnings from the project that have industry-wide value, and describes the additional development needed before the technology can be further advanced.

The California Public Utilities Commission (CPUC) passed two decisions that established the basis for this demonstration program. The CPUC initially issued D. 11-12-035, Decision Establishing Interim Research, Development and Demonstrations and Renewables Program Funding Level, which established the Electric Program Investment Charge (EPIC) on December 15, 2011. Subsequently, on May 24, 2012, the CPUC issued D. 12-05-037, Phase 2 Decision Establishing Purposes and Governance for Electric Program Investment Charge and Establishing Funding Collections for 2013-2020, which authorized funding in the areas of applied research and development, technology demonstration and deployment (TD&D), and market facilitation. In this later decision, CPUC defined TD&D as “the installation and operation of pre-commercial technologies or strategies at a scale sufficiently large and in conditions sufficiently reflective of anticipated actual operating environments to enable appraisal of the operational and performance characteristics and the financial risks associated with a given technology.”

The decision also required the EPIC Program Administrators to submit Triennial Investment Plans to cover three-year funding cycles for 2012-2014, 2015-2017, and 2018-2020. On November 1, 2012, in A.12-11-003, PG&E filed its first triennial Electric Program Investment Charge (EPIC) Application at the CPUC, requesting $49,328,000 including funding for 26 Technology Demonstration and Deployment Projects. On November 14, 2013, in D.13-11-025, the CPUC approved PG&E’s EPIC plan, including $49,328,000 for this program category. Pursuant to PG&E’s approved EPIC triennial plan, PG&E initiated, planned and intended to implement the following project: EPIC Project 2.28 with the purpose of developing and demonstrating a new technology to continuously monitor, analyze/diagnose and identify RFI that impacts the 400 MHz, 900 MHz and future 2.4 GHz[1] AMI network as well as develop an end-end process from monitoring-to-mitigation of such interference.

Through the annual reporting process, PG&E kept CPUC staff and stakeholders informed on the progress of the project. The following is PG&E’s final report on the project.

[1] 2.4 GHz network was anticipated to be deployed for meter communications in 2019 and could have been included in the project.

3 Project Summary

The RFI Monitoring Tool/Application had been targeted to 1) Conduct an initial noise assessment to establish a baseline of RFI in the AMI Network, 2) Analyze a continuous flow of data to identify potential locations and sources of RFI, and 3) Develop an end-to-end process/tool from monitoring to mitigation of interference. This tool would include the development of new algorithms to identify package damage and/or loss due to RFI and correlate the timing of the interference with transmission from other entities that use the same or nearby frequencies. This would be achieved through the ability to monitor and record 400 MHz and 900 MHz SmartMeter™ data packet transmissions and radio frequency spectrum histograms, and creating algorithms that would leverage data within existing AMI networks and internal spectrum analyzers imbedded in PG&E's existing SmartMeter devices. The application would include a user interface with heat maps to visualize the spectrum within PG&E's territory. The development of the process to utilize the application and to address any RFI identified is the key objective of the demonstration.

3.1 Issues Addressed

Today, PG&E relies on an ad hoc field tool and manual RFI reports upon request, which creates a challenge to understand the full scope of RFI issues or to measure the benefits of any potential mitigation approach.

PG&E's AMI networks use radios with frequencies in the range that are common to other users (i.e., emergency/medical, households) to transmit data required for billing of customers, outage detection and Volt-Var optimization. One 900 MHz AMI network operates in the 902-928 MHz range, an unlicensed[2] spectrum, which is open for public use. In many cases, small devices are transmitting at 1 Watt or less, however it is available for entities licensed up to 30 Watts. Another PG&E's 400 MHz communication network uses two licensed frequencies (462.4125 & 467.4125 MHz), but there are entities that operate radios using frequencies very near those frequencies. Therefore non-PG&E applications could have an impact on PG&E operations.

Transmissions from other entities can overpower or interfere with PG&E's AMI meter transmission, resulting in packet damage or loss, which causes the metering devices to 'retry' the transmission. Sometimes the device may have to 'retry' several times. If the transmissions do not succeed, the billing systems have to estimate portions of the bill. If there is limited historical data available, the billing operations team will estimate the bill manually. Communication issues may also lead to a field technician needing to make a trip to the meter and perform an investigation and/or replace the meter.

The current process for addressing RFI issues can have significant impacts on reliability and affordability due to 1) Manual labor of network specialists to run reports and complaints from operations to indicate potential interference, 2) truck rolls and field visits to verify the issue by technicians, 3) reducing the number of estimated bills per month and manual fixes resulting from non/intermittent communications from the SmartMeter™ to PG&E head-end, and 4) Impacts to the SCADA System.

[2] Unlicensed frequencies are public and do not require registration. On licensed frequencies, users register with the Federal Communications Commission (FCC) and pay for frequency use.

If RFI issues were to occur on the SCADA network, they could potentially impact critical grid monitoring and control operational functions, which in turn could impact grid reliability.

If RFI issues were to occur on the AMI networks, they would potentially reduce the efficacy of billing data collection, outage detection and Volt-Var optimization by causing disruptions to the stream of available data from AMI meters.

An interrupted data stream is a key issue as the utility moves towards the development of smart grids that require increasing amounts of real- time information.

If PG&E could monitor the transmissions that are causing interference to metering data transmissions, problems would then be mitigated in a timely manner. This could become increasingly important as technology continues to advance and more users become active on these radio frequencies that are being used at PG&E.

3.2 Project Objectives

The project objective was to develop and demonstrate a new technology to continuously monitor, analyze/diagnose and identify RFI that impacts the 400 MHz, 900 MHz and 2.4 GHz AMI networks as well as develop an end-end process from monitoring-to-mitigation of such interference. Such a new technology and application demonstration could have potentially reduced the instances of 'estimated bills' and improved network performance and reliability. This technology demonstration could have been used in the SCADA network to potentially mitigate RFI impacts to SCADA system and network.

The project included the following major tasks. Each task is sequential and builds on the previous work:

1. Leverage spectrum analyzers to establish a network wide baseline of RFIs.
2. Develop an algorithm and application to proactively identify potential RFI affected areas utilizing network RF data.
3. Mobilize probes to identify and confirm noise and RFI sources, which verifies that the demonstration application is working as intended.
4. Develop an end-to-end process from monitoring to mitigation of interference. As appropriate, take actions and next steps in accordance with FCC rules and guidelines.

3.3 Scope of Work, Projects Tasks and Milestones

The scope of work for this project included tasks that support the end result of demonstration of a new technology to continuously monitor, analyze/diagnose and identify RFI. To complete the Scope of Work for the project, Table 1 describes the project milestones and tasks that were created.

Table 1 – Project Milestones and Tasks

Milestone	Description	Deliverables
1	Initial Noise Assessment	a. One Signal Analyzer for Consultant b. One Signal Analyzer for PG&E c. Computers, Antennas, Mounting Kit, other Materials needed to complete RFI Probe Consultant d. Computers, Antennas, Mounting Kit, other Materials needed to complete RFI Probe PG&E e. Noise testing at 4 locations

		f. Technical Workshop for Initial Noise Assessment g. Noise Assessment Report
2	Algorithm and RFI Monitoring Tool	a. One Integrated RFI Probe for Consultant b. One Integrated RFI Probe for PG&E c. RFI Probe Communication and Measurement Algorithm based on automated test scripts d. Demonstration of RFI Probe usage e. Technical Workshop for Demonstration of RFI Probe
3	RFI Server Application Software	a. RFI Application Server hosted on a web service b. RFI Application Software with functions and features as described in the EPIC 2.28 project business plan c. Technical Workshop for Scalability Requirements and Architecture. d. Technical Workshop for Demonstration of RFI Server Application Software e. Demonstration of RFI Server
4	Noise Assessment Utilizing Application Software	a. End-to-End Operational Process for use of RFI Probe and RFI Server b. New Noise Assessment using RFI Probe and RFI Server c. Technical Workshop for Definition and Categorization of RFI sources d. Updated Noise Assessment Report
5	Trend Analysis	a. New Noise Trend Feature available in RFI Server Application Software b. Technical Workshop for Trend Analysis and Predictive Calculation
6	Predictive Calculation	a. New Predicative Feature of RFI noise levels based on modeling assumptions available in software
7	Link Assessment	a. New data import software feature to accept link data via PG&E Operational API from application head ends b. Definition of Link Assessment data strategy and technical requirements c. Link Assessment Algorithm d. Technical Workshop for Link Assessment e. Link Assessment Report
8	Final Report	a. Final report

4 Project Activities, Results, and Findings

This project sought to develop and demonstrate a new technology to continuously monitor, analyze/diagnose and identify radio frequency interference (RFI) that impacts the 400 MHz, 900 MHz and 2400 MHz networks as well as develop an end-end process from monitoring-to-mitigation of such interference.

4.1 Technical Development and Methods

A plan was developed to achieve the objectives of this demonstration project. This plan included the development of a network configuration that would enable PG&E to gather relevant data from external sources through a secure tunnel onto PG&E's network. This methodology also included identifying the minimum required data points and sources of this data to pursue the technology demonstration, the discovery of this data onto a PG&E RFI server, and software/algorithm development to provide and end-to-end tool to identify and mitigate RFI issues. With this framework, PG&E worked through the project tasks and milestones developed (Section 3.3) to satisfy the objectives of this project.

Network Architecture

Figure 1 shows the proposed network connections for the 2.28 SG Communications Path Monitoring technology demonstration. The network configuration external sources include AMI network & RFI Probe (Spectrum Analyzer) data. These data are communicated to the PG&E Network through the public telecomm network via VPN tunnel for security. Discovery of these data sources are required to be developed in order for the disparate datasets to be integrated into the RFI Server application with algorithms developed. After development of algorithms and an end-to-end process, the technology demonstration would provide RFI Data products such as heat maps to identify sources of RFI and interference mitigation processes (e.g. RF filters, directional antennas). An RFI user interface was also in scope of this project for effective operation and control to manage RFI at the employee level.

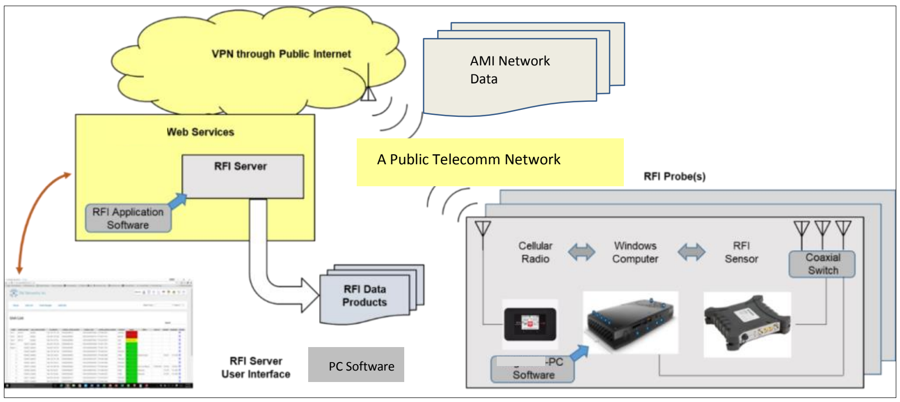

Figure 1 – High Level Network Diagram

Data Input Requirements

To develop and demonstrate the new technology and application, Table 2 lists the minimum continuous RFI network data points necessary for an end-to-end monitoring and mitigation tool. This data is expected to identify potential RFI areas for investigation and resolutions, and development of algorithms and review of the dataset would likely lead to additional data points to fully execute the demonstration.

The AMI Network and Spectrum Analyzer data have similar monitoring points, however the main differentiation is that the AMI network data includes data related to the PG&E Network only, and the spectrum analyzer data encompasses the PG&E Network data and all other interference properties outside of this network. It is believed that by overlaying the spectrum analyzer data on the PG&E Network data, PG&E could identify the source of interference as attributed by PG&E's internal RF networks or an external source.

Network Data Points
Uplink (UL)/downlink (DL) modulation
Channel load
UL/DL packet error rate/bit error rate
RSSI reads
UL/DL throughput
UL/DL Ping loss
Aggregate noise floor
AP to Relay latency data/reports
Others TBD

Table 2: Minimum Data Points to create and End-to-End Solution

Discovery
Two processes were planned for discovery, one from a spectrum analyzer computer application and the other from smart grid AMI head-end systems. Discovery is a key area of technical development since data is being collected from multiple systems into the RFI Server with unique specifications for each network device and differences in their output format. Being able to integrate this information in useable format to develop an end-to-end process from monitoring-to-mitigation of RFI is critical to the success of the demonstration. Details of the two planned discovery processes are as follows:

1. Spectrum analyzer computer application web service discovery – This process was planned for:
    - Parsing of CSV data files from a spectrum analyzer computer application as required for data storage and data presentation.
    - Parsing of TXT setting files from a spectrum analyzer computer application as required for data storage and data presentation.
    - Recording of RFI spectrum analyzer location based on latitude / longitude from a telecomm carrier's wireless mobile hotspot or from a GPS dongle.

2. Flat file discovery – This process was planned for:
    - Flat-files that contain source data generated by a head-end system.
    - Parsing of CSV/TXT data files from a head-end system as required for data storage and data presentation/integration.

Once the above processes are developed, each needs to be configured to properly discover each of the data types and then integrate them as necessary in the RFI server.

Algorithms, Software Development, & User Interfaces
Algorithm and software development is key to the successful execution of the objectives of this project. Without the ability to understand, analyze and interpret the dataset to develop algorithms and predictive models to mitigate RFI issues, no end-to-end solution can be created. The algorithm and software application will provide an automatic tool to routinely scan the networks, obtain and analyze necessary dataset, and then apply algorithms to identify potential RFIs. This application is the front end process to trigger subsequent steps for field-troubleshooting, confirming and mitigating of identified RFIs.

4.2 Challenges

PG&E successfully determined that the minimum data input requirements needed to develop and algorithm and application were not available. PG&E was unable to obtain RFI data through our head-end network center or through our third party vendor who manages our network. As a result, there was no feasible path forward for the project team to overcome the lack of data to demonstrate a successful application for proactive automated interference detection. Such an application would have the potential to demonstrate a technology solution for a consolidated insight into multiple AMI networks' RF states.

Lack of Available Data
PG&E was unable to obtain RFI data through our head-end network center and third party vendor who manages PG&E's network to procure this dataset. The vendor communicated that they did not have this information and were unable to provide support services to the requested dataset. It was confirmed that no specific RF tools existed to identify RFI signal(s) in PG&E's NAN. As a courtesy

service, the vendor provided channel loading data for a small area in San Francisco, however they were not optimistic that PG&E would be able to move into algorithm development with limited data.

Table 3 shows a sample dataset report provided to PG&E from AMI server for the first 11 channels (total 83) of a SmartMeter. The table describes loading (% packets transmitted) per channel and signal strength. This data provided is a summary log of packet transmission and the intervals of time occurrence for these packets of transmissions are not recorded or archived.

Notes: txg (transmit good); txf (transmit failed); rxd (transmit received); Min_rssi (Minimum RSSI value indicating signal strength

Channel	Txg	Txf	Rxd	Min-rssi
0	1267	112	1208	-98
1	1171	92	1091	-98
2	1333	111	1264	-106
3	1263	103	1157	-107
4	1494	150	1323	-97
5	1601	122	1440	-101
6	1197	136	1120	-96
7	1356	101	1230	-114
8	1257	130	1092	-107
9	1648	169	1265	-96
10	1718	139	1388	-102

Table 3: Transmitting Failed vs RSSI

In figure 2 below, the blue curve and green curve indicate the direct relationship of weak RSSI signal and failed transmitting of an RF signal. Weak signals will generate a high number of failed transmitting signals. The X-axis indicates the channel number. The Y-axis indicates the number of failed transmitting packages (txf) and its –dBm (min_RSSI). Although this data may provide insight into establishing a network wide baseline for RFI in our network, the lack of continuous monitoring and available data to execute a complete end-to-end tool restricted algorithm development and the ability to identify RFI, or provide holistic learnings on the issue.

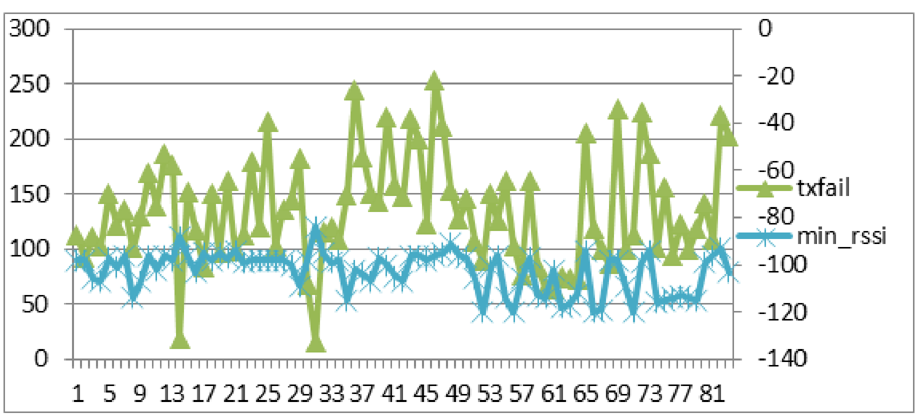

Figure 2- Direct relationship of weak RSSI signal and failed transmitting of an RF signal.

4.3 Results and Observations

PG&E activated spectrum analyzers and collected a sample of RFI data in our 900 MHz network. Review of this preliminary data indicated that there are instances where RFI may impact communications in PG&E on certain channels within the 900 MHz AMI network, but without establishing a network wide baseline noise assessment covering all times of everyday, it is not known to what degree or how this issue may escalate over time as more devices are included into these AMI networks.

900 MHz System Observations

Figure 3 is a screenshot of a short video clip of spectrum analyzer data that was obtained measuring signal strength (dBm) in one AMI network (900MHz – 930 MHz). This graph represents a waterfall feature that has a 3D image (X-freq + Y-dBm + Z-Time ms). The red and blue colors represent that a strong and weak signal are present respectively. A greater density of red reflects a higher probability that interference in the RF network is present. It is important to note that from this information the source of interference (red signals) cannot be determined. Also, until the field investigation and confirmation is performed, the specific RFI impact is not known.

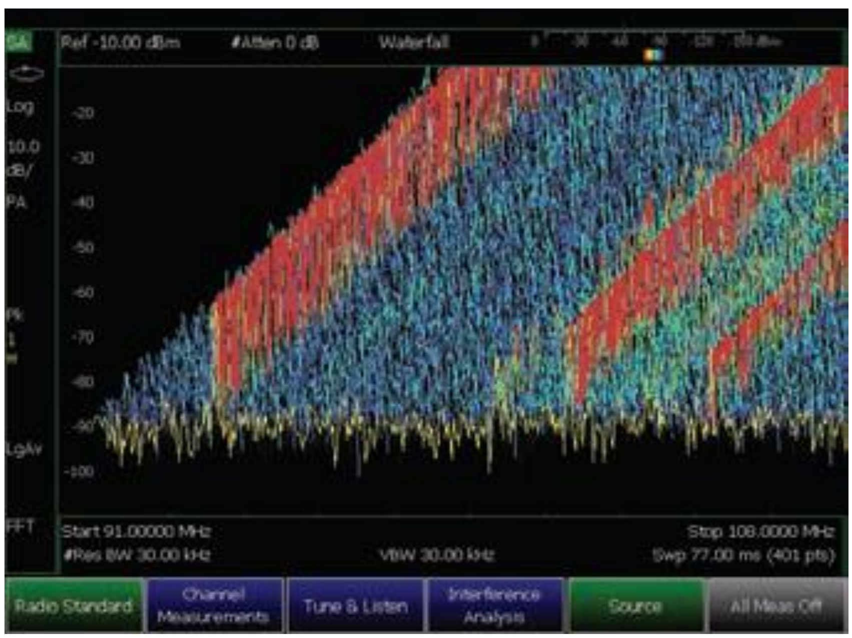

Figure 3 – High Level 3D RFI Signal

400 MHz System Observations

The following table provides example of the RSSI data that the 400 MHz network equipment records each time it receives the data and 400 MHz signals. These signal levels are what the network equipment heard at the moment it receives the data from its sources of the data transmission. This RSSI value is not the level of RSSI that comes out of the device.

The RSSI in table 4 has the range from -96 to -115 dB. Below -100 dB is good and -110 to -115 dB are marginally good. This RF dataset of RSSI is the only information available in the 400 MHz network and does not provide a complete RF dataset that is necessary for the development and demonstration of the RFI software application with algorithms and predictive models.

RSSI (dB)
-99
-108
-115
-112
-97
-109
-109
-104
-106
-98
-99
-110
-98
-99
-97
-96
-96
-102
-113
-112

Table 4: 400 MHz RSSI Signals

Data Analysis

Data validation was completed for the limited information available on both the spectrum analyzer and AMI/smart grid head-end reports for the purposes of creating a possible algorithm using such obtained data. Below are key observations of the data available for review.

Observations: Spectrum Analyzer Data

- RF signals from all systems that exist in the airspace of the spectrum analyzer coverage area.
- RF signals are continuously being scanned in the millisecond time frame for the 902-928 MHz frequency range. This high resolution is likely required to identify the source of interference that the AMI data set is unable to replicate.
- Some of the RF signals that appeared to have high RSSI and repeated in a quick succession.
- Lack of signal characteristic/property information.

Observations: AMI Network Data

- Data reports are one time scanning (Not a continuous scanning of frequency range like a spectrum analyzer). The lack of interval and frequent availability of necessary RF dataset may pose challenges in detecting RFI for the purposes of algorithm development.

- There is a high probability of when network cards are scanned at request; it will miss the periodic RF signals.
- Timestamp for AMI data are at a higher scale than a spectrum analyzer; therefore, this data cannot be overlaid on spectrum analyzer RF dataset that are at a higher resolution for learnings.
- Visual observations are required to confirm assumptions made between the AMI and Spectrum Analyzer data due to resolution issues. These assumptions would produce a higher percentage of error, thus limiting the ability to create accurate algorithms to develop and end-to-end RFI tool.
- Lack of signal characteristic/property information when the AMI network is in RF scanning mode (i.e. limited data points are available).

Both spectrum analyzer and AMI network dataset need to have some of the crucial information to build a functional algorithm. Based on the current data available, this information was not explicitly available or could be ascertained from the available information. The key questions that need to be answered from the data are described below. This information, among those that may have yet identified, would be critical to build the algorithm and provide the answers to the following questions.

- Where is the RFI located (with GPS coordinate)?
- When does RFI occur and how often?
- Who owns the suspected RFI signal?
- Why does RFI exist?
- Is such RFI on a licensed or unlicensed frequency?

5 Value proposition

5.1 Primary Principles

The primary principles of EPIC are to invest in technologies and approaches that provide benefits to electric ratepayers by promoting greater reliability, lower costs, and increased safety.

Affordability/Reliability – The ability to automatically identify and mitigate RFI through an end-to-end process would have minimized non/intermittent communications from SmartMeters™. Non/intermittent communications from SmartMeters™ lead to gaps in billing and metered data that result in customer bills being manually estimated. The continuous monitoring system proposed could potentially eliminate the labor required for manual fixes. As mentioned earlier in the report, if RFI issues were to occur on the SCADA network, they could potentially impact critical grid monitoring and control operational functions, which in turn could impact grid reliability. If RFI issues were to occur on the AMI networks, they would potentially reduce the efficacy of billing data collection, outage detection and Volt-Var optimization by causing disruptions to the stream of available data from AMI meters. An interrupted data stream is a key issue as the utility moves towards the development of smart grids that require increasing amounts of real- time information.

More specifically, this EPIC project would have contributed to the primary principle of greater network reliability by:

- Leveraging spectrum analyzers to establish a network wide baseline of RFIs.

- Developing an algorithm and application utilizing network RF data (including a user interface with heat map) to identify potential RFI affected areas.
- Mobilizing probes to identify and confirm noise and RFI sources, which verifies that the demonstration application is working as intended.
- Developing appropriate data file formats and data files to provide inputs for modeling calculations. Developing and including in the new application the predictive model of noise levels by year and specifying which noise levels will impact the communication operations for specific spectrums. Demonstrating alternative solutions for RFI remediation and filtering methods in the predictive modeling tool for measuring effectiveness of various RFI resolutions.
- Developing an end-to-end process from monitoring to mitigation of interference. As appropriate, taking actions and next steps in accordance with FCC rules and guidelines.

5.2 Secondary Principles

EPIC also has a set of complementary secondary principles. This EPIC project would have contributed to the Efficient Use of Ratepayer Funds principle (one the three secondary principles - societal benefits, economic development, and efficient use of ratepayer funds).

Efficient Use of Rate Payers Monies – A continuous RFI monitoring and analysis system may reduce the need for site visits and potentially for meter replacements. Additionally, network specialists rely on manually run reports and complaints from operations to indicate potential interference. The continuous monitoring system proposed would have automated this manually run process to identify interference.

5.3 Accomplishments and Recommendations

5.3.1 Key Accomplishments

Although the project did not enter the algorithm engineering and RFI Server build phase to commence execution of the algorithm development, key learning was achieved to build an important foundation for future work. The following summarizes key accomplishments of the project:

- Developed a network configuration plan that would enable PG&E to gather relevant external data sources through a secure VPN tunnel onto PG&E's network.
- Identified minimum data points and sources of this data needed to identify the source of RFI and develop a proactive automated detection algorithm.
- Identified two methodologies for data discovery into the proposed RFI server.
- Activated spectrum analyzers to identify and confirm noise and potential RFI signals in the San Francisco Test Area.
- Conducted an initial assessment on the available spectrum analyzer and AMI data sets to understand deficiencies and barriers associated with using this data to identify RFI and developing algorithms to create an automated end-to-end tool.
- Identified that the key data elements sought to pursue algorithm development are not being managed or archived and thus not available.

5.3.2 Key Recommendations

It is clear that in order for the algorithm to be executed in the future and be successful, necessary data elements are required to evaluate RFI issues and their associated characteristics. Raising the potential issues of interference and communicating its importance should lead to infrastructure to proactively and continuously monitor key RF data elements that can be analyzed to point out potential RFI.

5.4 Technology transfer plan

A primary benefit of the EPIC program is the technology and knowledge sharing that occurs both internally within PG&E, and across the other IOUs, the CEC and the industry. In order to facilitate this knowledge sharing, PG&E will share the results of this project in industry workshops and through public reports published on the PG&E website.

Potential Information Sharing Forums:

1. DistribuTECH
   New Orleans, LA | February 2019

2. Edison Electric Institute and Association of Edison Illuminating Companies (AEIC)
   Indian Wells, CA | October 2018
   TBD | April 2019

3. Bi-annual California IOU Metering Services Managers Info Sharing Sessions – Alternates between PG&E, SCE, SDGE

5.5 Data Access

Upon request, PG&E will provide access to data collected that is consistent with the CPUC's data access requirements for EPIC data and results.

6 Metrics

The following metrics were identified for this project and included in PG&E's EPIC Annual Report as potential metrics to measure project benefits at full scale.[3] Given the proof of concept nature of this EPIC project, these metrics are forward looking.

D.13-11-025, Attachment 4. List of Proposed Metrics and Potential Areas of Measurement (as applicable to a specific project or investment area)	Reference
1. Potential energy and cost savings	
c. Avoided procurement and generation costs	Section 3.1 – Potential future secondary benefits
3. Economic benefits	
a. Maintain / Reduce operations and maintenance costs	Section 3.1
c. Reduction in electrical losses in the transmission and distribution system	Section 3.1 – Potential future secondary benefits
e. Non-energy economic benefits	Section 3.1
4. Environmental benefits	
a. GHG emissions reductions (MMTCO2e)	Section 3.1 – Potential future secondary benefits
5. Safety, Power Quality, and Reliability (Equipment, Electricity System)	
a. Outage number, frequency and duration reductions	Section 3.1 – Potential future secondary benefits

Table 5: Project Metrics

[3] 2015 PG&E EPIC Annual Report. Feb 29, 2016. http://www.pge.com/includes/docs/pdfs/about/environment/epic/EPICAnnualReportAttachmentA.pdf

7 Conclusion

Given the data access limitations, there was no feasible path forward for the project team to demonstrate a successful algorithm based application for proactive automated interference detection. Although a small sample of channel loading data was obtained for a small test area in San Francisco, the lack of continuous data points and resolution of this information restricted algorithm development and the ability to execute a complete end-to-end RFI solution. However, the preliminary work completed on this project could be leveraged in the development and/or use of future tools and in forming strategies around broader prevention of AMI network RFI. This includes:

- Review of preliminary interference that demonstrates there are instances where RFI may impact communications in PG&E 400 MHz and 900 MHz AMI networks.
- Development of network architecture that would enable PG&E to gather relevant external RFI data sources through a secure VPN tunnel onto PG&E's network.
- Identification of the minimum data points and sources of this data that would be needed to identify the source of the RFI and develop a proactive automated detection algorithm.
- Identification of two methodologies for data discovery into the proposed RFI server.

Future work that would be needed once the necessary data becomes available from the network provider would include establishing the network wide RF Baseline noise level going forward in order to understand the rate of growth in RFI and the levels of RFI impact in the AMI network operations, development of an algorithm to automatically detect the interference and its source, and development of the utility processes around operationalizing how that application is used to mitigate the potential interference issues in line with Federal Communications Commission (FCC) rules and guidelines.

Although PG&E was not able to move forward with development of a full system solution, PG&E was able to identify through a sample of RF data in a geographic location that there is potential channel congestion that can lead to RFI conflicts in our network. With increasing numbers and types of devices that will occupy the limited unlicensed bandwidth of AMI networks in the future, RFI issues have the potential to reduce the efficacy of billing data collection, outage detection and other important utility functions by causing disruptions to the stream of available data from AMI meters.

As the broader utility industry moves towards further expansion of AMI, the collection of RFI data needs to be a prioritized requirement of the network vendors to ensure utilities have the data they need to monitor and proactively mitigate these emergent interference issues. These results will be shared with PG&E's network provider as well as the broader industry to help inform the need for this important data in the future.