Leveraging Full Band RF Capture to Improve the Customer Experience and Operational Performance

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
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Overview

Technological advances in full band RF capture (FBC) create an opportune time for the development and presentation of intraday spectrum analytics. FBC is a breakthrough technology that eliminates the traditional tuner concept associated with previous cable modem single chip SOC designs, by allowing direct conversion of the complete 1 GHz downstream spectrum. This technology provides the most flexible, deployment friendly solution possible, by removing channel lineup limitations through the use of a front end tuner design, that allows the device to utilize any downstream frequency without adjacent channel restrictions or specific capture band with windows.

Along with the new FBC functionality comes effective new diagnostic features allowing Operators to remotely view the RF spectrum of their network and also the device itself. This advanced spectrum analyzer allows for nonintrusive remote analysis of weak signals, interference, tilt and other suboptimal performance parameters to help reduce operational expenses (OPEX) by eliminating unnecessary truck rolls and calls into the call center.

The unprecedented visibility into full band RF spectrum provides a tremendous opportunity to collect analyze and amass spectrum data into actionable metrics. By attaining, aggregating and enriching RF data with other Operator information, preemptive, noninvasive troubleshooting can occur from remote locations to mitigate RF issues for all households passed in the Operator's plant, before customers are impacted. Additionally, a signature profile can be created for each device to record RF patterns and subsequently compare back to device birth certificates and other pristine baseline devices. The creation of these historical spectrum records from the customer's devices will enable predictive analytics to further empower Operators to prevent possible issues. Ultimately the opportunities for Operators to reduce service costs and improve the overall customer quality of experience are tremendous.

CPE based Full-Band Capture and Spectrum Analysis

What It's All About

The demands on the modern Hybrid-Fiber Coax network are increasing at an exponential rate. For subscriber access, the Cable industry has implemented RF channel bonding using the DOCSIS specification. This practice has allowed Operators to increase bandwidth to the subscriber in order to support the natural human condition for 'more'; more data, more video, more gaming…more everything. With the advent of 'more', the responsibility to properly support that fundamental requirement increases disproportionately, requiring Operators to increase their attention on performance.

Operators therefore, are constantly looking at ways to provide improved and more efficient means to support the services they offer while balancing the cost. Having the

ability to proactively monitor the network is a must. Being able to extend that capability and complete the loop inside the home is a breakthrough. Remote monitoring and field diagnostics have come a long way in the past few years, as has an ever-increasing ability for the Operator to monitor the access network. The latest Advanced Wireless Gateway designs have allowed for proactive, non-intrusive support to further monitor the network in its entirety.

With the implementation of CPE-based full-band digital tuning technology, we can now capture spectrum data at the subscriber premise. This is a significant advancement in the Operator's ability to survey the entire RF footprint of the access network. In addition to trouble shooting, RF spectrum analysis provides the operator the ability to monitor the physical plant at various locations in that network for real-time, proactive health assessment.

Digitizing the analog signal has allowed the ability for the CPE to capture the entire downstream spectrum (Figure 1) to facilitate the analysis of the RF signal more efficiently than using multiple analog tuners. This digitization allows Operators the flexibility to deliver more services at a lower cost while also providing the opportunity for remote signal analysis (SA) *(question: do you mean signal analysis here? If so, please spell out as SA is not as common of an acronym)* diagnostics.

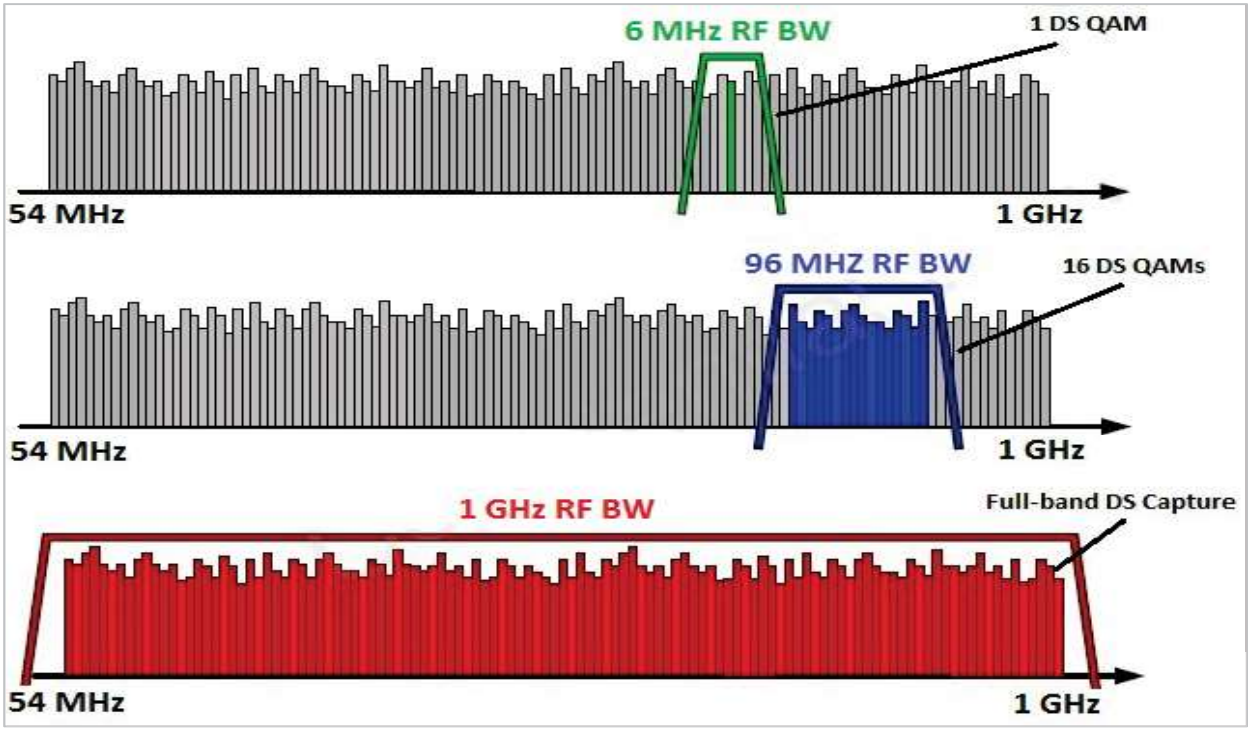

Figure 1 – Digitization of the analog signal

The digital "front-end" tuner design evidenced in Figure 2 allows the device to use any downstream frequency (54-1002MHz) for snatching data without the need for specific "capture bandwidth window" and for bonding channels without any adjacent channel

restrictions. Consequently, with the complete RF signal in digital form, advanced signal processing techniques can be used for tuning and diagnostics which in turn allow the complete view of the downstream spectrum for all lines of business.

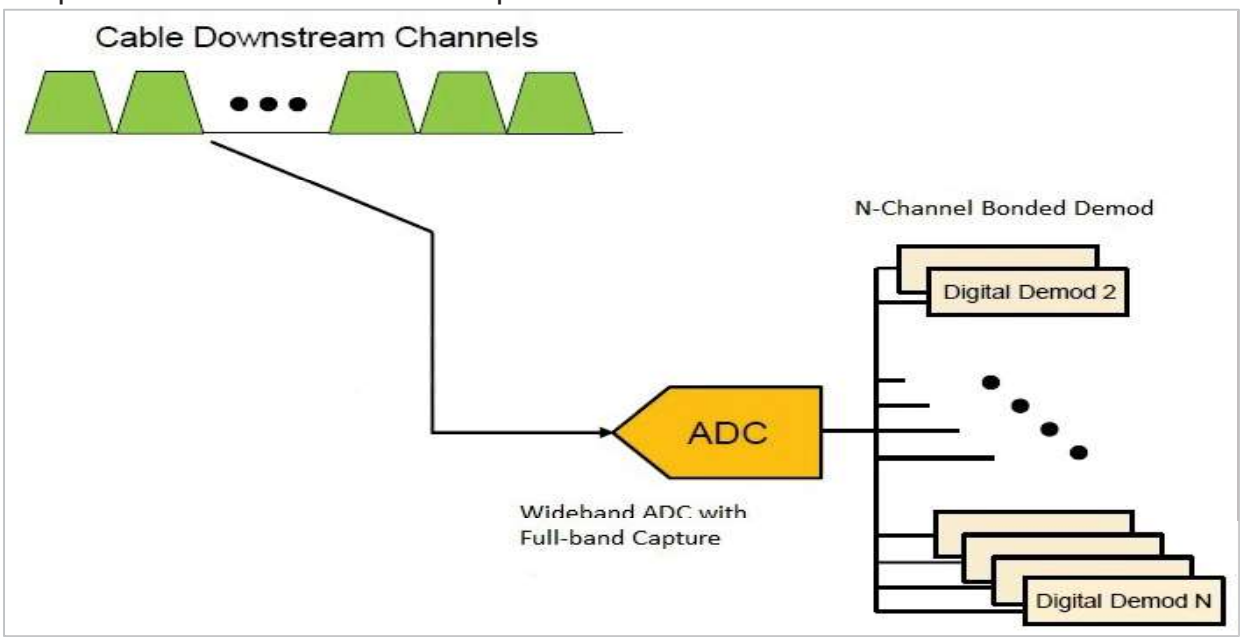

Figure 2 – Digital Front End Tuner

A basic function of spectrum analysis is Fourier transform. This process transforms a signal in the time domain into a frequency domain. The Discrete Fourier Transform (DFT), in turn converts a finite list of samples into the frequency domain. These computations can then be handled by dedicated hardware that implements Fast Fourier Transform (FFT) to quickly and efficiently calculate spectrum data in a format that is usable by Operators (Figure 3).

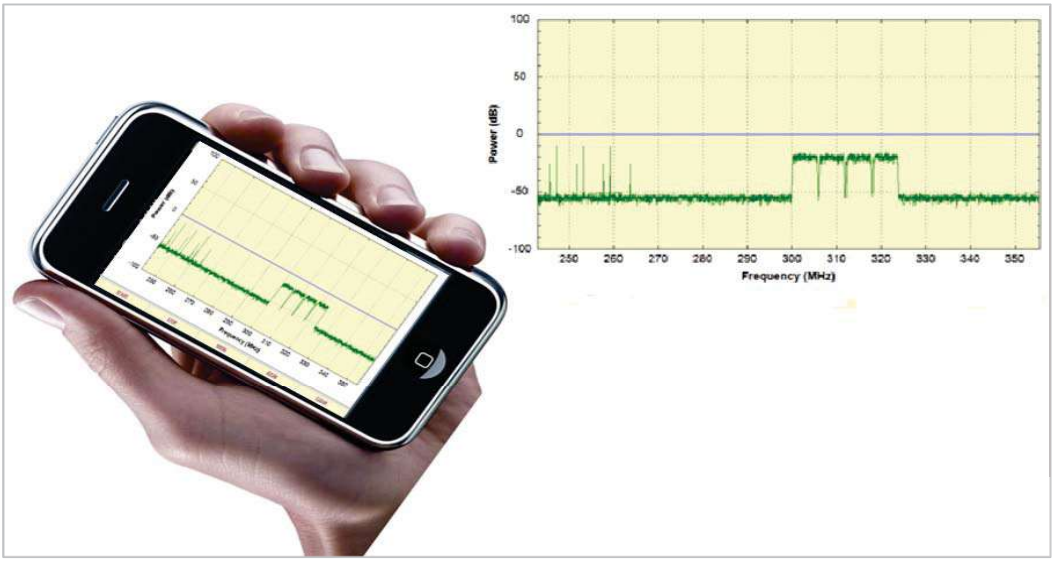

Figure 3 – Spectrum Data Calculations via FFT

The ability to capture the full spectrum bandwidth and provide the data is transparent to the user. The implementation of this technology does not interfere with any user processes and does not affect the services delivered to the subscriber. On-chip memory and the hardware itself performs the FFT analysis in order to offload any resources needed to support customer data and other requirements the device might need for normal operations.

Advanced In-Home & Network Diagnostics

When needed, certain parameters can be configured to narrow the focus of the spectrum data being analyzed. The entire spectrum can be viewed or we can construct certain spectral maps to look at sections of the whole; we can modify the frequency, the span of our search, amplitude, bandwidth and channel power measurements to focus in on certain sections of the spectrum. This becomes invaluable when troubleshooting in real-time or capturing data across a window of time in order to better diagnose issues that are otherwise difficult to discover.

Based on the capability to view the entire downstream spectrum and focus our sight on specific blocks in real-time, we can capture data in a couple different ways. First, we can view the RF signal real-time via a web-based GUI. While this provides immediate visibility into the spectrum, instant collection of data and a sexy graphical interface, it is limited in its ability to analyze the data over a certain period of time. This is where the second and more power mechanism to capture the data provides the potency of this technology…welcome our tried-and-true friend to the party; SNMP.

So what exactly is SNMP? Well SNMP stands for Simple Network Management Protocol, which is an Internet standard for managing devices on an IP network. Operators design network management systems in their back-office environment that implements the SNMP standard to expose device-specific management and configuration data in order for the Operator to manage thousands and sometimes millions of devices deployed in their network.

Via the SNMP protocol and supporting MIBs the built-in spectrum analysis (SA) function can collect data at specific times or continuously throughout the day and change operating parameters to grab exact data sets when required. Advanced diagnostics are capable based on the ability to capture the entire downstream spectrum and its data. There are several data types that can be monitored, captured and analyzed on a per device basis:

- Frequency
- MER
- Signal level
- Correctable/uncorrectable errors, BER
- SNR

- Channel equalization monitor
- Frame lock
- QAM constellations

The capability to capture and analyze this data on a single device provides the Operator with the ability to check along the cable plant to identify issues that would normally be difficult to find. If this technology is installed at various points in the network, detailed remote monitoring is accomplished efficiently and at a very low cost. Statistics can be collected throughout the neighborhood, node and further upstream to detect where exactly the problem is occurring. The Operator can then determine if problems are local to the home or the node or the larger global network and thus optimize their workforce to have the right technician sent to the right location.

When separate, seemingly disparate small issues can be consistently captured, large problems in the network can be correlated and become evident and fixed in a directed, preemptive nature.

Proactive Network Troubleshooting

Typically, Operators are only aware of a spectrum issue inside the home when a customer calls. Quite often this issue presents itself within the plant, e.g. RF problems. This is reactive customer support and causes customer dissatisfaction and a significant portion of an Operator's OPEX. Pre-emptive network investigation and associated non-invasive troubleshooting using the devices installed throughout the network and in the home would therefore be extremely powerful.

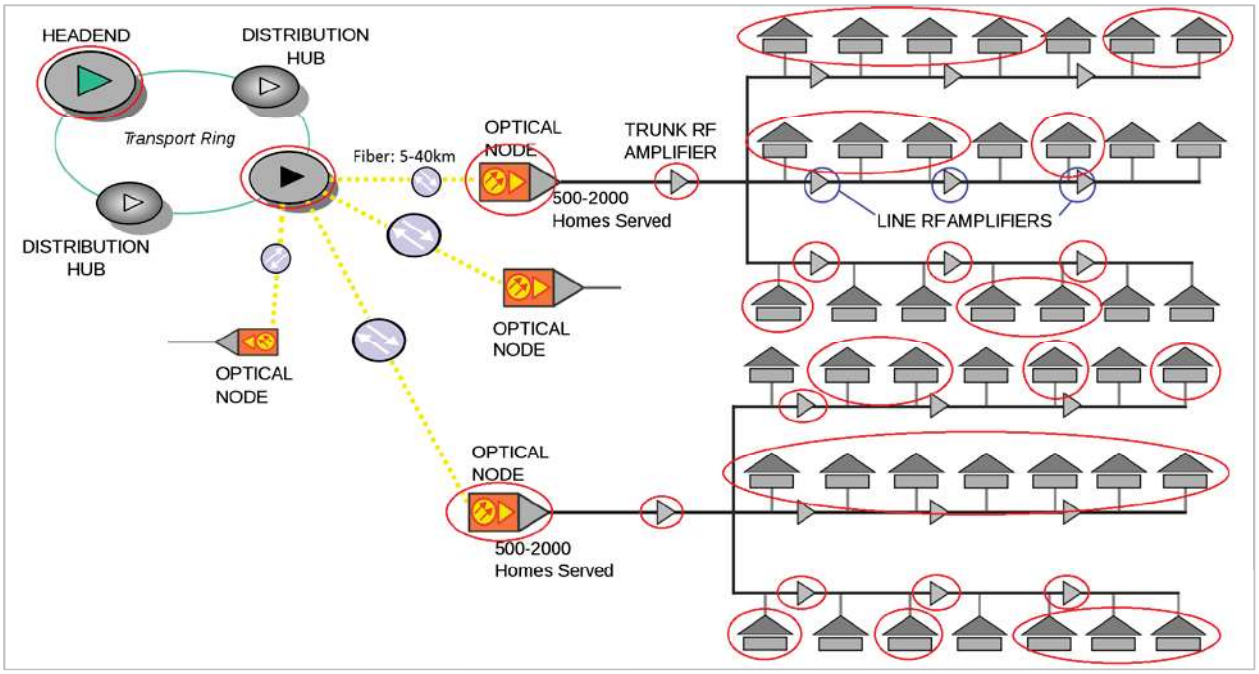

Figure 4 – FBC Device Placement within the HFC Network

CPE devices that support full-band spectrum capture and the analysis of the data can be installed throughout the HFC network. This implementation allows the Operator and its support systems to obtain a clear and definitive map of the entire RF from the Headend to the home. Figure 4 identifies all the various points in the HFC network that low-cost FBC devices can reside.

While tools and software have been developed to identify major network outages, it is the accumulation of the smaller issues that are very difficult to detect, distinguish between anomalies and subsequently fix. Likewise, intermittent issues are even more difficult to identify and categorize as a problem. Many times those sporadic and irregular problems are missed all together, when in fact they are causing customer performance/satisfaction issues and could be symptoms of much larger outages yet to come.

By capturing spectral data via the CPE both over time and across the entire network, a vast array of data can be analyzed on a continuous basis and studied by intelligent software tools to expose behaviors in the overall network not previously known. This type of intelligence also allows for targeted network fixes. Advanced tools can comb through a "cable line" and diagnose exactly where the problem is and subsequently dispatch the right technician to the correct spot and resolve the issue immediately.

Various RF issues can have different impacts on the services delivered throughout the access network. Having the ability to capture data at various points in the network will allow the operator to categorize and prioritize service-impacting issues based on RF impairments. RF impairments that can be discovered remotely by CPE-based SA toolsets can be proactively resolved before larger more global issues become customer impacting. Various problems that can be resolved due to continuous monitoring and correlation of the data include but are not limited to:

- Bad amplified module
- Old and/or faulty plant equipment due to aging and environmental stress
- Poor home wiring due to poor quality coaxial cable
- Broadcast outages
- Reversed splitters and improper filter installation
- Overdriven QAMs
- Faulty taps and amps due to damage
- Superfluous signal ingress

The ability to acquire this type of data and classify it in a meaningful way and then translate that into the intelligent business decisions will increase the efficiency of the access network and the workforce supporting it. Over time, the Operator will be able to determine which issues in the network have what impact on specific services. Those issues that have greater affect on the subscriber (or the network) can be given greater

importance when troubleshooting and alarming. When trends expose themselves based on the aggregation of similar issues, escalation rules can be implemented within the toolset to make the right decisions promptly.

The explosion of commercial services has also increased the necessity for intelligent proactive support systems. The service level agreements required by commercial customers are more stringent than other lines of business; therefore having the ability to detect and resolve issues before they become customer impacting is a fundamental requirement in providing such products and a key competitive differentiator.

While current support tools can discover equipment in the home that is offline or without a battery, tools to proactively monitor the network, have the intelligence to evaluate data over time and create information to make decisions and take action is limited. Having the ability to identify issues with CPE and correlate that data with RF anomalies and what would normally be insignificant variations in the plant therefore is extremely compelling.

These types of tools and the capabilities that CPE-based spectrum analysis provides will empower customer service organizations to analyze the information and make intelligent decisions in order to dispatch technicians to precise locations at the right time. We can all agree that less time should be spent trying to find the problem while more time is spent proactively fixing the problem. The goal of maintaining 99.999% up time can only be achieved if problems are fixed before they become customer impacting.

Targeted analysis, intelligent decisions and proactive resolution is the end game.

New Technologies Bring Enhanced Capabilities

For many years, Operators have been able to remotely read and marginally analyze Internet and telephony spectral data by procuring the raw amplitude data from the Management Information Base (MIB) files within their customer's modems and advanced wireless gateways. While valuable, the business and operational intelligence provided to the Operators from the Internet and telephony spectrum provided only a small portion of the spectrum as it was devoid of the video frequencies within the full spectrum.

Throughout the last decade, Operators have utilized digital video compression transmitted to Digital Consumer Terminals (DCTs) to distribute video content to their customers. Until recently, measuring the magnitude of the input signal versus frequency within the full spectral range at the DCT was not possible from a remote location. Instead, many Operators had insight into the video spectrum only through the use of a hand held spectrum analyzer capable of monitoring one home at a time.

Similar to the analysis currently performed on the Internet and telephony spectral data, it is critical for Operators to be able to measure the power of the video spectrum of both known and unknown signals in order to provide the clearest, most reliable video signal to their customers. Providing robust full bandwidth RF spectrum analytics for all households passed from a remote location, will obviate truck rolls to the home by arming engineers with the advanced intelligence they need to mitigate signal issues before they impact the customer.

Thanks to the advanced functionality of the new FBC chipset detailed above, it is possible to explore how to use the newly available RF spectrum data en masse to both reduce service costs and improve the customer Quality of Experience (QoE). The acquisition, aggregation, enrichment and propagation of FBC data into recurring reports and web services applications will allow Operators to evolve from a service centric approach to a customer centric one by leveraging integration, centralization and big data. An architectural overview of the spectrum data acquisition processes will be provided first, followed by a deeper dive into the analytic methodologies and capabilities.

Architectural and Technological Foundations to Data Acquisition

Acquisition of Amplitude Data

There are multiple approaches to both procuring the raw amplitude data from the FBC modem and gateways and loading that data, along with other applicable Operator data, into a database for analysis. The following is one architectural approach that has been used and successfully deployed to obtain, enrich, store and publish full band amplitude data.

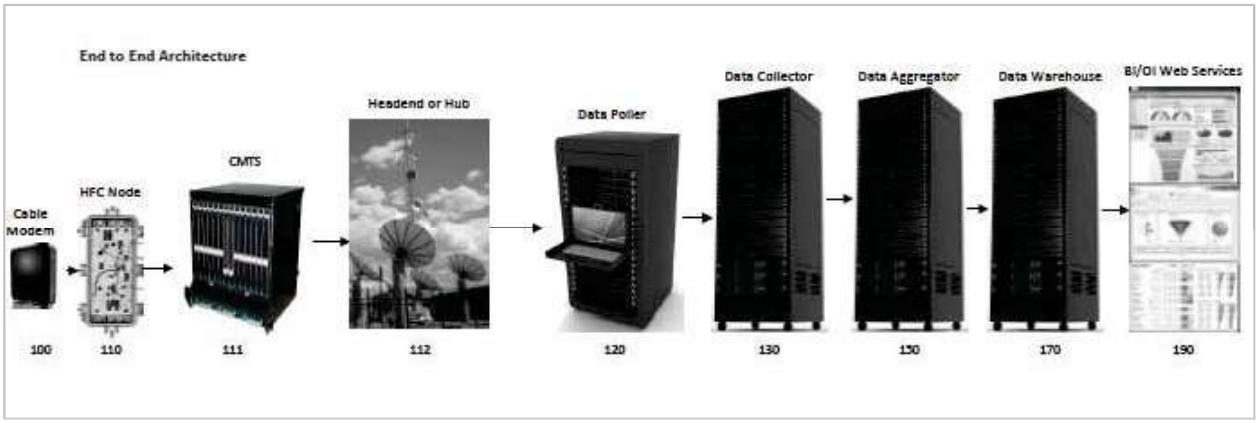

Figure 5 – End-to-End Architecture for Amplitude Data Acquisition and Storage

As shown in Figure 5, the data acquisition process begins with the polling of the raw amplitude data from the FBC Cable Modems **100**, through the HFC Node **110**, where the data is temporarily stored in the Cable Modem Termination System (CMTS) **111,** which reside in the Operator's Headends **112.** The Data Poller **120** then interfaces with the CMTS to collect the raw amplitude data from the MIB, which files are written to the CMTS from the Cable Modems at configured intervals throughout the day. Once the Data Poller collects the amplitude data files from the CMTS', it will process and store the data. Most Operators already have a defined polling schedule in place, i.e. an Operator may schedule intraday polling of all DOCSIS modems hanging from their CMTS' every four hours using a blast SNMP call. In order to procure sufficient data in support of recurring spectrum analytics, it is recommended that a minimum of 4 polls per day be scheduled.

Next, the Data Collector **130** pulls the processed data from the Data Poller and routes it through a decoder protocol to convert the amplitude data from its original hexadecimal format to decimal notation. Upon completion of the decoding of the amplitude data files, the data is parsed, sorted and appended to multiple fact and dimension data sets for analysis. Fact tables are generally numeric and contain the measurements, metrics or business events or states such as employee ids in a Human Resources database. Dimension tables qualify facts and are designed to contain dimension keys, descriptive attributes, and values such an employee's department, name and location in that same Human Resources database. The Data Aggregator **150** should then pull the processed data from the Data Collector at scheduled intervals into the Data Warehouse **170**.

The Data Warehouse is the main data repository for a Web Services Application **190** that can be used to publish the spectrum analytics**.** This Web Services Application may be an internal system already resident to the Operator or may be constructed externally to house and publish the spectrum analytics. Utilizing a Web Services Application to publish the spectrum analytics provides a centralized repository for all potential users of this data from Headend and Network Operations Center (NOC) Engineers to Network Technicians, Tier 2 CAEs and leadership team members. If the Operator does not currently maintain an internal web services application in which this data can be published, an external system should be designed that provides both business intelligence insights to the spectrum analytics along with operational support tools.

Continuing on with the Data Warehouse design, multiple data marts are constructed inside of the Data Warehouse to store small slices of data to transmit records more efficiently to the Web Services Application**.** Examples of some of the data marts that may exist within the Data Warehouse include:

1. Time data mart - enables analysis by multiple periodicities.
2. Billing data mart - enables analysis by the data attained from the Operator's billing data warehouse.
3. Plant data mart - enables analysis by the Operators' plant topography such as headend, node CMTS etc.

4. Customer data mart – enables analysis of specific customer data and allows correlation of customers who may have related problems or correlation to specific network equipment and/or services.

As noted above, the Web Services Application may be an internal toolset already in use by the Operator that can be updated via a feed from the Data Warehouse or the Application may also be an externally built system. More details will be provided below about the Web Services Application and the spectrum analytics contained therein.

Acquisition of Operator Data

The ability to provide Operators with context based spectrum analytics requires the acquisition of additional data beyond the amplitude data from the DOCSIS 1.X, 2.X and 3.X modems. Required elements from the Operator include billing data containing the Operator's customer attributes such as the street address, headend and node of their dwellings, along with the appropriate details for their devices and products. The Data Aggregator should then be configured to import all of this data into the Data Warehouse for processing.

The acquisition of these additional Operator datasets will be critical to enriching the amplitude data in the quest to provide meaningful analytics. For example, by procuring the customer's MAC addresses, locations and product data and joining it to the intraday amplitude data, it is possible to provide a geographic readout of Internet and telephony spectrum performance for all households with DOCSIS modems resident to the home and the same geographical readout can be provided on video spectrum performance for any households with a FBC modem in home. Many more details will be provided below on the vast possibilities that can be derived with full band spectrum data.

Spectrum Analytics

Enough of the architectural nuts and bolts and onto the exciting stuff – analytics! As customer Quality of Service (QoS) and Quality of Experience (QoE) continue to be an important focus for Operators, new tools and methodologies to help maintain service reliability become ever more important. Consequently, the analytic capabilities afforded to Operators by this breakthrough visibility into the full band RF spectrum should be implemented with expediency.

Preemptive and Noninvasive Troubleshooting

Creating and deploying enhanced toolsets to internal Operator teams can provide increases in both operational efficiencies and customer satisfaction. One of the primary mechanisms to realizing these increases is utilizing spectrum analytics to preemptively address video and other spectrum issues before they impact customers. Historically, when a customer's video signal was experiencing ingress, LTE interference, signal to noise issues etc., one of the only ways to identify and correct the issue(s) was by

sending a technician to the customer's home. The technician would then connect a spectrum analyzer to the service drop to look for issues with the spectrum, review the signal strength and quality, and check for any corresponding issues one channel at a time.

Today, with the spectrum and cable data that is now housed in the Data Warehouse, intraday reports and real time views in the Web Services Application can be generated and pinpointed geographically at the street level that detail video spectrum health for all CEA channels and all households passed with an FBC Modem. These video spectrum health reports are predicated on the union of the intraday polling of the FBC DOCSIS modems and the Operator's billing and network topology data. The analysis can then be presented at a variety of aggregation levels including at the individual household passed, or the entire node, headend, market, region etc.

Imagine being an engineer in the headend or NOC and having the capability to view video spectrum heath for all households passed on any node or distribution leg within your footprint. Now take that a step further to understand that these very same engineers could remotely conduct a variety of troubleshooting protocols in the network on any node evidencing spectrum pattern variances and if appropriate roll a network tech to address the issues at the exact distribution leg or amplifier evidencing discrepancies. The intraday visibility into the full band spectrum provided by these processes will support this noninvasive troubleshooting before the customers are impacted and subsequently contact the call center.

In summary, these efforts to enrich and monitor the downstream spectrum will provide ubiquitous awareness of network and customer issues real-time, for the video, Internet and telephony products. Correlating the RF data with applicable market data and publishing it in a continuously refreshed Web Services Application then creates preemptive, noninvasive, actionable behavior for improved operational effectiveness and customer experience.

Business and Operational Intelligence Possibilities

At this point it should be apparent that the technological advances provided by the visibility into the full band spectrum provide another opportunity for Operators to evolve from a service centric to a more customer centric approach. The business and operational intelligence possibilities derived from spectrum analysis will allow the Operators to establish, analyze and troubleshoot detailed empirical data regarding plant health and consequently their customer's experience, for all products. Let's dive a little deeper here, into those business and operational intelligence possibilities.

Device Signature Profile

One of the exciting new possibilities of the full band capture chipset is the opportunity it provides to create a device signature profile. With the creation of a

device signature profile for each FBC DOCSIS modem deployed in customer's homes, power supplies and headends, Operators can attain enriched troubleshooting capabilities visible in the Web Services Application through their triangulation efforts.

The triangulation activity begins when a full band spectrum snapshot is taken of each FBC device at the time of its first installation on the Operator's network. This birth certificate snapshot is tagged with the device MAC address, and the date and time of the snapshot, which data is then stored in the Data Warehouse. It is presumed that at the time of the very first installation of the FBC device, that the amplitude data files should serve as a historical reference from which to compare the device's behavior over time.

The second source of the triangulation activity is acquired from other pristine baseline FBC devices installed in the Operator's network. Each of the predetermined pristine baseline FBC devices should be included in the intraday polling schedule performed by the Data Poller. Per best practices, the amplitude files of these baseline devices should also be tagged with the device MAC address and the date and time of the polling.

The third source of triangulation occurs from the ongoing intraday polling of the FBC devices installed in customer homes throughout the network. Subsequent to being decoded, the amplitude data for these devices should be compared in the Data Warehouse, back to their birth certificate and correspondingly to the baseline devices in the headend in which they reside. The algorithms for these comparisons are designed to look for any center channel frequency variances across all frequencies within the full band spectrum of the FBC device. When spectrum variances are found that could potentially drive service disruptions to the Operator's customers, proactive alerts can be provided both on the Web Services Application screen and to the NOC and headend engineers via SMS, Email or other preferred notification protocols.

The identification of these variances at the individual FBC device level (for which the location, node and distribution leg is known from the billing data in the Data Warehouse) when compared back to the pristine baseline device, allows for the assessment of the depth and breadth of the variance to ascertain whether it is isolated to a single device, street, distribution leg, node, etc. The corresponding result of the triangulation efforts afforded by the device signature profile then, allows the appropriate engineers to preemptively stabilize the network while simultaneously warding off potential customer impacts.

Predictive Analytics

In addition to the Device Signature Analysis efforts outlined above, a secondary benefit to storing all of the amplitude data for each device in the Data Warehouse

is the ability to establish spectrum anomaly patterns over time. As the historical amplitude-file data marts grow with the passing of time and the Operators install larger numbers of FBC devices on their networks, so too grows the ability to examine center channel frequency variances for patterns.

As any one center channel frequency in an FBC device's RF spectrum begins to evidence service impacting variances such as frequency suckouts, standing waves, ingress, SNR, etc., the amplitude data for that device can be tagged and documented in the Data Warehouse. Over time, a complete library of major spectrum variances can be established and corresponding analysis can transpire to catalog the behavior of the center channel frequency prior to the inception of the variance. These catalogs can then be used to generate predictive models, which will exploit the patterns found in the historical amplitude data to compare to current intraday polling files. The net result of these efforts will be the ability to generate predictive analytics within the Web Services Application to proactively notify the Operator's engineers that a spectrum fault may be about to begin and thus provide the ability for the Operators to address a future impacting issues before a customer even notices it. This is indeed the future of network operations and significantly improved customer experience.

Spectrum Reports, Dashboards and Views

The volume of reports, dashboards and views in the GUI, hereinafter referred to as reports, that can be produced within the Web Services Application from the joining of the full band spectrum data with other Operator data are innumerable. This includes business intelligence reports needed to understand KPIs, historical trends, goal trending etc., along with the operational support reports that provide real time updates to engineers and support personnel. With the Operator's network topology, channel lineup and billing data that is stored in the Data Warehouse, the spectrum analysis reports can be aggregated by node, headend, market, region, division etc. Some samples of the possible reports that could be created from the full band spectrum analysis that would provide immediate value include:

- Product Status (based on spectrum health) by customer type – residential, multiple dwelling unit or small business - pinpointed geographically at the street level as evidenced in the top of Figure 6 below.

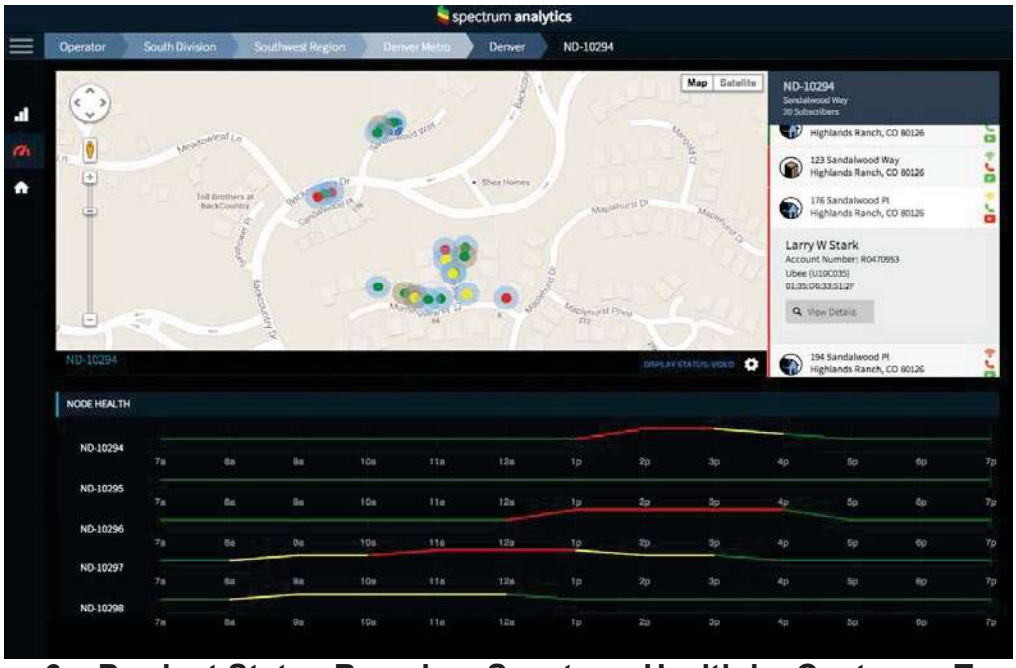

Figure 6 – Product Status Based on Spectrum Health by Customer Type

- Hourly node status based on spectrum health as evidenced in the bottom of Figure 6 above.
- Analysis of modem models or firmware driving recurring impacts.
- Assessment of issues with certain center channel frequencies based on the feed from the programmers.
- Graphical readouts of center channel frequency variances at the device level (in yellow), when compared to a pristine baseline device (in green) with possible error causes and solutions as evidenced in Figure 7 below.

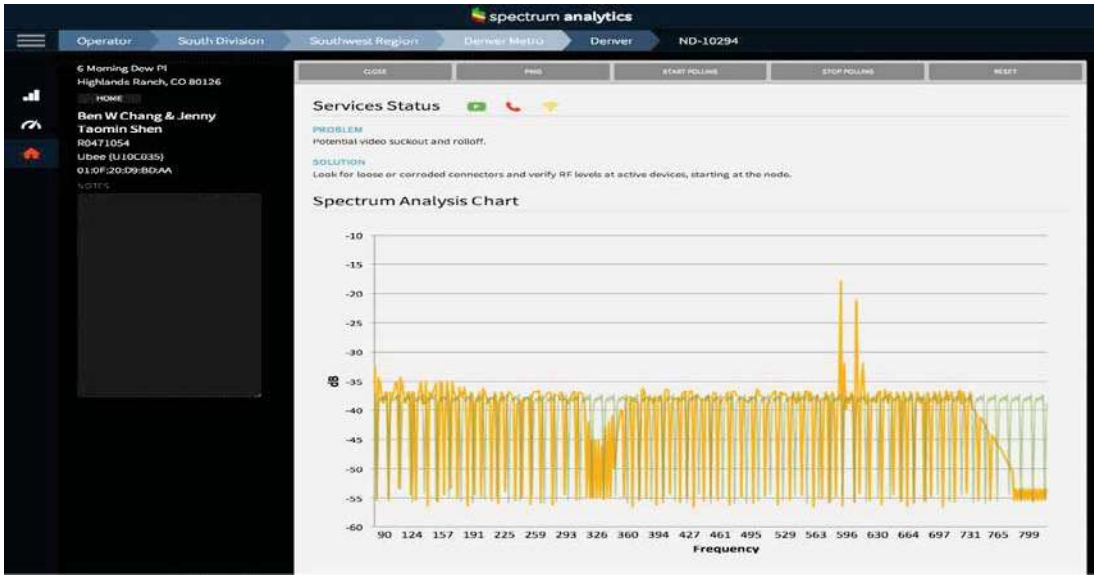

Figure 7 – Center Channel Frequency Variances for Impacted Customers

- 24 hour, weekly, and/or monthly network availability uptime based on empirical knowledge/spectrum variances.
- Corrected and uncorrectable packet errors by node and device type.
- Analysis of truck roll percentages/call center activity before and after utilization of spectrum analytics for preemptive troubleshooting.
- Overall Bit Error Rate (BER), Modulation Error Ratio (MER), Signal Level/Strength, Signal to Noise Ratio (SNR), Channel Equalization Monitoring, Frame Lock per node and percent of impacted nodes.
- 24 hour, weekly, and monthly snapshots of Node & CEA channel performance compared to goal.
- 13 month rolling reports for forecast and budgeting on all critical metrics.

Clearly, the above list represents only a small portion of the potential analytics that will be available to Operators by leveraging the new full band RF technology, integration, centralization and big data, but all of these reports will provide greater full band spectrum visibility and operational capabilities than are available today.

Implementation

"Now that we have all this intelligence what do we do with it?" is a question that naturally evolves from the development of these spectrum analytics. The task at hand really is to transform data from information to knowledge to wisdom for operator's support teams. Consequently, in addition to the suggested reports, dashboards and web services views suggested above, operators should determine appropriate spectrum thresholds for each product line, in order to use the data in a correlated fashion. When combined with the appropriate business rules, the time to analyze and mean time to repair any spectrum issues should be significantly reduced.

The establishment of such spectrum thresholds could vary by headend or region but once implemented, will serve to pinpoint variances outside of the expected thresholds. Business rules should then be applied and prioritized against the denoted thresholds to activate certain actions amongst cable operators support personnel. For example – thresholds could be set to send an SMS/email alert to the appropriate personnel when X devices in a node or Y devices within a headend evidence service impacting variances. The initial support personnel who receive the alert should be provided with suggested mitigation steps and an expected time to address the issue(s). Should the issue not be able to be resolved within the expected timeframe, a technician should be dispatched to the impacted areas to reduce potential customer impacts. Analysis should be compiled on an ongoing basis to assess needed threshold changes and areas of improvement/further training within these processes.

Return On Investment (ROI)

The marriage between hardware implementation and application based analysis can deliver to Operators, meaningful customer data correlation and competitive differentiation in their ongoing quest to provide QOS and QOE to their customers. The ability to attain real-time, remote spectrum visibility for all products, including video, via the enhanced technology of the FBC chipset, enables operators to identify and mitigate spectrum issues before they drive customer impacts.

Never before have Operators been able to establish empirical data regarding node health for the full forward spectrum. The advancements of the full band capture chipset however, enable operators to do so remotely while decreasing the number and time to mitigate channel and node issues. A natural byproduct of this improved troubleshooting capabilities then, is decreased traffic into the call centers, corresponding reductions in trouble calls to the home and the potential reduction of the purchase and inventory of handheld spectrum analyzers and other sweep systems tools.

When calls do come into the call center and trucks do need to roll to the home, application based toolsets like the spectrum analytics Web Services Application can provide call center agents with the ability to validate customer claims of channel impairment. Additionally, technician's troubleshooting capabilities can be enriched through the Web Services Application by helping them determine to a much greater degree than just using a handheld spectrum analyzer, the extent within the node and corresponding distribution leg of the signal degradation(s). The operational support system functions within a Web Services Application can also provide the technician with visibility into all CEA channels on the node to determine the range of the impact.

Finally, as Operators strive to stabilize their networks through these technological capabilities and other methodologies, it is critically important to be able to baseline initial performance and then monitor trends and improvement percentages. The application-based analysis supported in the Web Service Application through enhanced spectrum analytics can provide cable executives with the needed visibility into their network KPIs along with the corresponding reports required to manage their annual network budgets, forecasts and goal trending.

Implementation/Operational Readiness Prep

The evolutionary advances in CPE-based full band capture that eliminate the traditional tuner concept associated with previous cable modem single chip SoC designs is currently undergoing lab evaluations and field tests with multiple Operators. To assure a successful deployment while maximizing benefits, Operators should take several steps to prepare their teams for this new spectrum technology and analytic capabilities:

- Define possible hardware implications for the capital management and warehouse teams, technicians and NOC/Headend engineers

- Operators should create pertinent training materials and support models for potential new users of mass RF Data within their daily operations:
    - **Repair Technicians** – With the advancement of a spectrum analytics Web Services Application, repair technicians will have visibility into the real-time health of each CEA channels' spectrum at the customer's home along with an understanding of the spectrum health of all other households passed within the node. Further, the Web Services Application will provide a readout of all CEA channels on the node, not just a single channel to which a handheld spectrum analyzer can be tuned which further enhances the technician's ability to troubleshoot and isolate the issue. Repair technicians will need education on how to use the application and how to analyze and apply in the field the information being displayed.
    - **Network Technicians, NOC & Headend Engineers** – Deploying a web based spectrum analytics tool will support the granular assessment of signal strength at a Headend, Node and Channel level. Visibility into the data at a network and individual device level will promote preemptive examination of weak signals, interference, tilt and other sub-optimal performance, while also supporting the proactive routing of network technicians to the exact node and distribution leg impacted. Historical spectrum data in the tool will promote preemptive assessment of current issues and corresponding training will need to transpire on all of the above functionality.
    - **Tier 2 Customer Account Executives (CAEs)** should be provided with a spectrum health view within their existing troubleshooting toolsets and receive the necessary training to use the information in addressing customer issues. In addition to attaining visibility into the spectrum health of the specific customer's device that they are troubleshooting, Tier 2 CAEs should also receive visibility into spectrum health for the entire node along with the capability to do a live ping of the FBC Modem to attain real time graphical readouts of the spectrum.
- In order to facilitate the deployment of the web based spectrum analytics, integration with Operators billing, network topology and channel lineup data will need to transpire in advance of the launch. Attaining direct query access or a recurring daily feed from the Operators will be most efficient.
- In order to provide subscriber counts within the Web Services Application based on activity within a specific CEA channel, Operators will need to maintain and provide their most current channel lineups by headend. Knowing that spectrum analysis toolsets are being developed, the best practice for Operators would be to consolidate channel lineups into a common database that can be maintained and integrated.
- Similarly, in order to provide network map based analysis and executive level reports, Operators will need to maintain and provide their most current Network topology data. For example, any time a node split transpires, an

updated network topology chart will need to be exported to the Web Services Application, in order to present an accurate network topology within the web services interface.

Conclusion

Due to the demand for increased subscriber services and the subsequent reliability of those services, the Operator has a significant challenge to be more proactive with their network support and ensure the best possible quality throughout the access network, including the home.

With the implementation of a front-end digital tuner the entire downstream spectrum can be captured by CPE devices throughout the network. This low-cost application of spectrum analysis is a very powerful instrument with the potential to realize meaningful alarms with predetermined solutions so that immediate actions can be taken and minimizing the impact to customers.

The benefits for CPE spectrum analysis are significant. The advantages of proactive RF analysis range from the simple but powerful ability to detect physical problems in a precise location in the plant to reducing repeat service calls to improve overall system performance.

Next-generation Advanced Wireless Gateways support this technology and can be installed at the home, at the business and other points throughout the network that give Operators the ability to proactively monitor the network remotely 24/7/365. Technological breakthroughs in the FBC chipset when combined with robust spectrum analytics derived therefrom, can promote service reliability and play a critical role in identifying and addressing full band spectrum variances.

Potential Considerations and Suggestions for Future Work

Considerations for further study:

- Cost/benefit analysis and quantification of return of investment of OpEx by proactive monitoring of the entire RF spectrum inside the home and throughout the access network:
  - Reduction in call volume
  - Lower risk of customer churn by increasing customer satisfaction
  - Increase in network performance
- Wireless/WiFi spectrum analysis. With CPE-based FBC and spectrum analysis we capture the RF on the subscriber side and upstream by implementing WiFi spectrum analysis we can further characterize the entire home network.
- Define the classifications of RF symptoms and correlate to service consequences, thus creating the possibility of business prioritization of workforce resources.
- Detailed cross-referencing and categorization of captured RF data at the CM and throughout the network and the correlation with other DOCSIS error to quantify consistent issues and their symptoms.
- Enablement of faster deployment of new services based on FBC analysis prior to deployment and even in product design.

Acronyms

BER – Bit Error Ratio

CEA – Consumer Electronics Association

CMTS - Cable Modem Termination System

CPE – Customer Premise Equipment

DCT – Digital Consumer Terminal

DOCSIS Cable Modem – Data Over Cable Service Interface Specification

FBC – Full Band Capture

HFC Node – Hybrid Fiber Coax

MER – Modulation Error Ratio

MIB – Management Information Base

NOC – Network Operations Center

QOE – Quality of Experience, a/k/a Quality of Service

RF – Radio Frequency

SNR – Signal to Noise Ratio

SOC - Selectable Output Control

About the Authors

Jon Schnoor is Director of Advanced Solutions Engineering for Ubee Interactive' s Advanced Wireless Gateway Organization. In his role he provides high-level engineering support for customers, direction for the Advanced Solutions Engineering team, facilitates new business development initiatives and supports product management in defining requirements for new cable technologies.

Prior to joining Ubee Interactive, he was Director of Technical Marketing at Hitachi Communications helping lead the Cable Industry's effort with EPON and the DPoE specification. Jon was a contributing engineer with the DPoE group at CableLabs helping to develop the industry's first fiber homerun requirements.

Jon has been in the cable and telecommunications industry for more than 19 years and prior to his involvement on the vendor side, Jon spent a majority of his career in the Operator space with various engineering groups. At Comcast, he helped design, test and deploy the single largest DOCSIS-based provisioning system in the world. At Charter Communications Jon lead voice deployments across Charter markets, including field network readiness and provisioning and was the technical lead for the Charter Home Networking product.

Jon holds a Bachelor's degree in Information Systems from Iowa State University and an MS degree in Telecommunications from the University of Colorado.

Christine F. Fiske is a 14-year veteran of the cable and telecommunications industry. At Profusion Analytics, Christine is the executive responsible for a broad scope of data technology solutions including designing and deploying interactive software and business intelligence platforms to improve productivity and operational and financial effectiveness for telecommunications clients nationwide.

For 11 years prior to joining Profusion Analytics, Christine held various management positions at Comcast Corporation and its predecessors. Most recently, Christine was responsible for directing the Billing, Reporting, Web Development and Serviceability teams in support of enterprise wide and local market initiatives. During her telecom career, Christine consistently managed systems integrations throughout the TCI, AT&T Broadband, MediaOne, Adelphia and Comcast mergers and owned many of the data, software engineering and billing functions of the companies' new product launches, SMATV acquisitions and operational improvement initiatives.

Christine is a long time member of SCTE and also sits on the Industry Advisory Board of the University of Denver's School of Engineering and Computer Science. Additionally, Christine has been an active member of WICT Rocky Mountain since 1999 and has served on the board since 2010. An active supporter of our military men and women, Christine has volunteered at the USO for many years. Christine holds a B.S. in Economics from the College of William and Mary and a Masters of Science in CIT from Regis University.