SPECTRUM EFFECT

Development of a National Spectrum Strategy

RFC Response

National Telecommunications and Information Administration (NTIA), Department of Commerce

Docket Number: 230308–0068

www.spectrumeffect.com

Table of Contents

1. INTRODUCTION

Spectrum Effect is pleased to respond to NTIA's RFC 230308–0068 and offer our vision for the Development of a National Spectrum Roadmap.

Spectrum Effect's state-of-the-art Spectrum-NET software solution has redefined how mobile operators mitigate RF interference affecting their networks. Spectrum-NET performs automated ML-driven analysis and closed-loop mitigation of RF interference and operates seamlessly across all RF bands and multi-vendor NR and LTE cells within mobile network on a continual basis using performance data reported from the RAN equipment without any external probes or sensors.

Spectrum-NET analyzes the proprietary performance data from the NR and LTE RAN equipment each reporting period (i.e., every 15 minutes). Spectrum-NET uses this data to characterize and classify the RF interference with Convolutional Neural Network (CNN) models trained using deep machine learning. More than 7,000,000 hours of labeled RF interference data from 50+ mobile operator networks were used to train the Spectrum-NET CNN models, resulting in the industry's highest accuracy solution for automatically classifying RF interference signatures.

Spectrum-NET performs closed-loop actions to avoid and mitigate RF interference within mobile networks. Spectrum-NET adjusts radio configuration parameters in response to RF interference and cell loading conditions. With O-RAN, Spectrum-NET can be operatized in real-time as an xApp on a RIC and to manipulate the 5G NR scheduler for more fine-grained control of UE's and customization based on the government's spectrum sharing requirements. In previous generations of RAN equipment, the scheduler was a proprietary implementation by each vendor and did not provide such controls.

With Spectrum-NET, mobile operators are rapidly resolving harmful RF interference, improving subscriber Quality of Experience (QoS), improving network KPIs, increase spectral efficiency, surgically deploying field resources, and saving significant CAPEX and OPEX. Spectrum-NET provides unparalleled visibility into spectral efficiency, quantifies performance by RF band and provides key insights for spectrum investment and strategy.

Spectrum-NET is widely deployed globally by mobile operators, ingests hundreds of PM counters for millions of mobile network cells every reporting period, and performs AI-driven analysis on this data to drive mitigation actions. Spectrum-NET will be deployed nationwide in the U.S. by 2 of the 3 largest operators in the U.S. by mid-2023.

Operating within private and public cloud environments, Spectrum-NET ingests large quantities of data generated by cellular networks and condenses this information into actionable information for monitoring the state of cellular networks and mitigating RF interference affecting cellular networks. This will facilitate next generation dynamic spectrum sharing, including sensing the presence of incumbent systems and predicting conditions that could cause harmful interference.

Spectrum Effect is partnering with thought leaders in the wireless space to develop a new breed of spectrum sharing applications. Spectrum Effect's industry-leading automated ML-driven RF interference analysis and mitigation technologies are now being applied to dynamically sense and avoid incumbent systems in spectrum sharing environments. This next generation spectrum sharing solution will be showcased in the coming months.

Spectrum Effect's RFC response highlights the technologies under development as well as the generally available Spectrum-NET solution, which is widely deployed by mobile operators.

Section 3 of this RFC response contains Spectrum Effect's vision for a new National Spectrum Strategy.

Sections 4-12 of this RFC response detail existing Spectrum-NET features, functionality, and capabilities.

2. ABOUT SPECTRUM EFFECT

Spectrum Effect's mission is to solve the most challenging and costly problems in the wireless industry through innovation and automation. With R&D centers located in Kirkland, Washington, USA, and San Pedro Garza Garcia, Mexico, the Spectrum Effect team is passionate about creating disruptive technologies, engineering excellence, and enhancing the experience of mobile operators. Spectrum Effect has created Spectrum-NET, the industry's leading solution for the automated analysis and mitigation of RF interference. Protected by 30 issued patents, Spectrum-NET performs machine learning-driven analysis of RF interference across all RF bands and operates seamlessly across multi-vendor NR and LTE cells within mobile networks continually. With Spectrum-NET, operators across the globe are automatically mitigating RF interference, improving network KPIs, surgically deploying their field assets, gaining insights into spectral efficiency, and saving significant OPEX and CAPEX. www.spectrumeffect.com.

3. A NEW VISION FOR A NATIONAL SPECTRUM STRATEGY

Spectrum Effect is pleased to offer the NTIA a new vision for its National Spectrum Strategy to ensure optimal use of spectrum resources by applying the industry's most advanced dynamic spectrum sharing technologies. These strategies will create a more standard operating environment, drive efficiencies, and increase non-federal spectrum access while safeguarding DoD missions. The NTIA can immediately act on these 8 strategy recommendations and be fully operational with the world's leading centralized spectrum management within the 18 months.

By applying this new vision for a data-driven approach to spectrum strategy along with the industry's latest sense-and-maneuver RF technologies outlined in this response, the U.S. government will be able to make new spectrum available rapidly and judiciously while ensuring optimal usage of valuable national spectrum assets. Enacting this vision will be a game changer for the U.S. government and mobile ecosystem, providing the U.S. with a sizable competitive advantage in the wireless space for 6G and beyond.

Spectrum Effect's Recommendations for the NTIA's Spectrum Strategy

1. **U.S. operators adopt a single AI-driven spectrum management solution.** This type of solution exists today (i.e., Spectrum-NET), and Spectrum-NET is already being deployed nationwide by two of the three U.S. tier-1 operators. Incentivize the remaining U.S. operators to adopt a common spectrum management solution to facilitate holistic data and information sharing required to successfully implement dynamic spectrum sharing at scale. Spectrum management capabilities are detailed in Section 4 and include:
    a. Automated analysis and mitigation of RF interference on a continuous basis.
    b. Seamless operation on all RF bands (shared spectrum and non-shared spectrum) across multi-vendor radio equipment and multiple technologies (NR, LTE, 6G).
    c. Ingestion of performance data reported regularly by the operator's Radio Access Network (RAN) equipment for analysis.
    d. Ingestion of network topology data and tailored analysis for each type of site (outdoor, indoor, power level, etc.).
    e. Machine learning to accurately classify RF signals and trigger mitigation actions.
    f. Enhanced visibility into spectrum resources including spectral efficiency, RF interference, and Quality of Service.
    g. Closed loop actions to maneuver spectrum resources and avoid RF interference.
    h. Dynamic sense and maneuver around incumbent systems in spectrum sharing environments.
2. **U.S. government communication systems adopt a common spectrum management framework.** Standardize on spectrum management framework across government systems and across RF bands where spectrum sharing is expected to occur. This could be achieved by implementing an instance of Spectrum-NET for each government communication system covering the specific RF band utilized. This spectrum management system will ingest proprietary RF performance data reports available for each government system, analyze the RF frequency/time usage and spectral efficiency of the system, and

analyze RF interference affecting the system. For each government system, an assessment will be performed to determine what can be reported and where opportunities exist to enhance reporting, with the objective of achieving similar AI-driven insights provided by tools like Spectrum-NET for mobile networks.

3. **Establish a new Spectrum Analysis, Strategy, and Planning Organization (SASPO) that jointly reports into both the NTIA and FCC.** This new organization will be responsible for:
    a. Deploying and operating the spectrum management solutions for mobile operator networks, private networks, and government communication systems into a centralized secure facility. This organization's secure data center will combine RF measurement feeds from all mobile networks and all government systems (e.g., data from NR cells in the same RF band will be seamlessly analyzed from across the T-Mobile, AT&T, and Verizon networks).
    b. Monitoring and tracking how spectrum is utilized by both the U.S. government and U.S. operators using solutions like Spectrum-NET. This organization's centralized solution will have a clear view of the spectral efficiency and utilization of spectrum resources in all geographic areas (including in historically underserved or disconnected communities such as rural areas and Tribal lands) for all licensed spectrum by U.S. operators and the U.S. government.
    c. Assuring incumbent operation in spectrum sharing environments.
    d. Measuring and reporting on use and efficiency of spectral resources to the FCC and NTIA to enable better strategic decisions on spectrum.
    e. Performing research and analysis on new wireless technologies deployed by the government and mobile operators.
    f. Addressing external RF sources affecting both the federal government communication systems and the licensed spectrum by mobile operators.
    g. Creating data-driven regulatory policy recommendations to enable a vibrant ecosystem in spectrum sharing environments.
4. **Dynamically share spectrum using the advanced AI-driven spectrum management solutions.** Apply the new common insights into government and operator spectrum utilization and leverage the advanced software frameworks for RF interference detection, analysis, and incumbent avoidance to enable dynamic spectrum sharing with optimal use of valuable spectrum assets. This centralized spectrum management and interference analysis will drive the decision-making for dynamic spectrum maneuvering. Focus initially on making available critical RF bands via spectrum sharing such as EMBRSS (3.1 – 3.45 GHz), since the EMBRSS is a logical extension to C-Band spectrum that has been licensed and is under deployment by U.S. operators.
5. **Adopt regulatory policies to enable more robust private networks using unlicensed shared spectrum resources. Private networks to adopt a single AI-driven spectrum management solution.** Establish new regulations for RAN equipment deployed using unlicensed spectrum in spectrum sharing environments (e.g., GAA in CBRS) to report RF interference data to a centralized system (i.e., a Spectrum-NET for private networks). Further, establish new rules of operation where those that invest in GAA have some level of performance assurance in terms of the RF interference environment. These shared

spectrum unlicensed band cooperation policies will enable optimal collective performance, provide preferential rights for the first to deploy in an area, and allow verification of targeted spectral efficiency and interference levels before spending on new deployments. These same policies and requirements can be applied to non-3GPP OFDMA-based RAN equipment for reporting per frequency ("per-PRB" as per 3GPP) interference measurements for each reporting period.

6. **Leverage the vast deployment of RAN equipment by mobile operators to measure and report on interference in adjacent government bands.** Establish new regulations for 5G/6G/7G RAN equipment deployed within mobile networks to receive, measure, and report on signals in adjacent RF bands used by government systems (e.g., NR C-Band radios could monitor the Altimeter band, NR PCS radios could monitor GPS spectrum, etc.). The centralized solution hosted by SASPO would then combine the interference measurement inputs from all the RAN equipment from all the mobile operators for comprehensive monitoring and tracking of interference signals affecting these government bands. This can be applied to ensure a clean RF operating environment for government systems without investment into deploying probes.
7. **Drive real-time monitoring and control within mobile networks and private networks for optimal spectrum sharing.** Incentivize U.S. operators to deploy a RAN Intelligent Controller (RIC) framework with additional real-time controls for RF interference mitigation and/or push requirements to the NR infrastructure vendors (e.g., Ericsson and Nokia) for these controls. The O-RAN Alliance is currently pursuing O-RAN use cases for maneuverability and traffic management. Spectrum-NET will soon be operational on a non-real-time RIC platform. Spectrum-NET will analyze PM data reported in an O-RAN environment with the same AI-driven approach used in a traditional RAN environment. With O-RAN, Spectrum-NET will operate in real-time as an xApp on a RIC and manipulate the 5G NR scheduler to avoid/mitigate RF interference in real-time and perform real-time spectrum maneuvering around incumbents.
8. **Serve as a world leader in setting global standards for spectrum management and equip allies with a common standardized framework.** Cooperate with allies of the U.S. for the adoption of a similar, centralized software framework for the analysis of RF for mobile operators and government communication systems. Establish cooperation treaties for cross-border RF interference scenarios due to RF band conflicts (e.g., Band 7 and Band 41) and tropospheric ducting conditions affecting TDD systems. Spectrum-NET is already deployed nationwide by an operator in Mexico and will soon be deployed nationwide in Canada. Spectrum-NET is widely deployed by mobile operators across the globe.

RFC Questions

The above strategy recommendations cover the following questions contained in the NTIA RFC:

- Pillar 1: Questions 5, 8, and 9.
- Pillar 2: Questions 2, 4, and 5.
- Pillar 3: Questions 2, 3, 4, and 5.
- Implementation Plan

4. STATE-OF-THE-ART ANALYSIS AND MITIGATION OF RF INTERFERENCE

Spectrum Effect's state-of-the-art Spectrum-NET software solution performs highly innovative automated ML-driven analysis and mitigation of RF interference across all RF bands and operates seamlessly across multi-vendor multi-OSS NR and LTE cells on a continual basis without any need for external probes. Spectrum-NET ingests and analyzes PM, CM and Topology data from Ericsson, Nokia, Huawei, ZTE, Samsung and Mavenir RAN equipment.

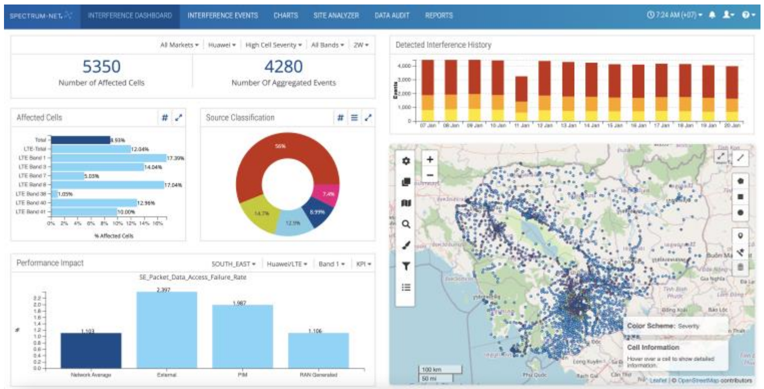


Figure 1 – Spectrum-NET Dashboard.

In response to RF interference affecting the mobile network, Spectrum-NET automatically drives parameter changes to optimize network performance for the affected cells, sectors, and sites. Spectrum-NET provides actionable events and drives processes to rapidly pinpoint and resolve the sources of harmful RF interference, improve network KPIs, increase network capacity, surgically deploy field resources, and save significant operational costs. Spectrum-NET provides an invaluable new perspective to operators on RF interference across its network, enhances visibility into spectral efficiency, quantifies performance by RF band and provides key insights for spectrum strategy and management.

Spectrum-NET is commercially licensed by mobile operators in North America, South America, Asia, Middle East, and Africa. Figure 2 shows the levels of RF interference experienced by more than 40 mobile operators in these different regions.

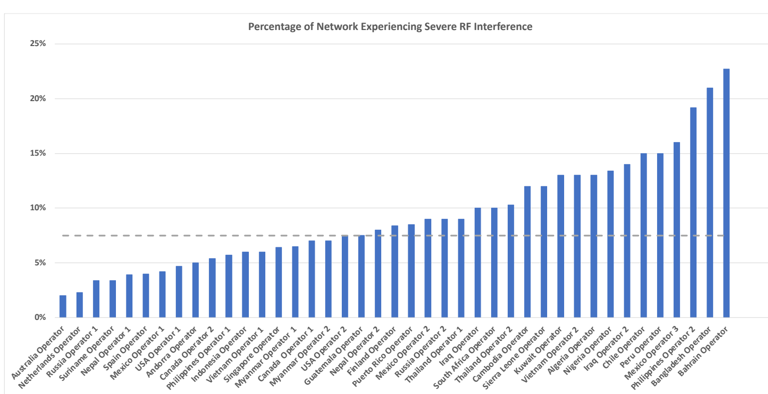


Figure 2 – Percentage of Cells Experiencing RF Interference in Mobile Operator Networks

The main categories of RF interference are shown in Table 1. Spectrum-NET analyzes performance data from mobile networks and automatically detects, characterizes, classifies, aggregates, locates, predicts, and measures the impact of RF interference from these sources. Spectrum-NET drives processes and triggers actions to resolve harmful RF interference and improve network performance. Spectrum-NET measures the impact of each interference event on network KPIs. Spectrum-NET calculates the interference severity for each interference event based on the characteristics of the event. The interference severity and impact assessment are key objective measures for prioritizing resources to mitigate the events.

RF Interference Categories		
External Interference BDA, CATV Egress, DECT, RFID Scanner, RF Jammer, Broadcast TV, FM harmonics, security camera, ,…	**PIM Interference** Internal (cabling, connector, antenna) and External (nearfield to the antenna) sources at the site.	**Cross Border Interference** Misalignment or inconsistent configuration of the RF band. Can occur during ducting.
TDD Self-Interference During periods of tropospheric ducting and during loss of synchronization.	**RAN Generated Interference (RGI)** From UE traffic. Requires Network Optimization.	**Faulty Hardware** Faulty radio units, Rx branches and crossed feeders.

Table 1 – RF Interference Categories.

Built on a Kubernetes-orchestrated microservices architecture, Spectrum-NET is a web-based, cloud-native, horizontally scalable solution with extensive mapping, visualization, and report generation capabilities. Spectrum-NET is readily deployable in public cloud, private cloud, and traditional server environments. Spectrum-NET can be integrated with other tools to maximize automation. Spectrum-NET supports SMO/non-RT RIC for greenfield and brownfield implementations. The Spectrum-NET software architecture is shown in Figure 3. Spectrum-NET runs online 24x7 and performs continuous interference analysis.

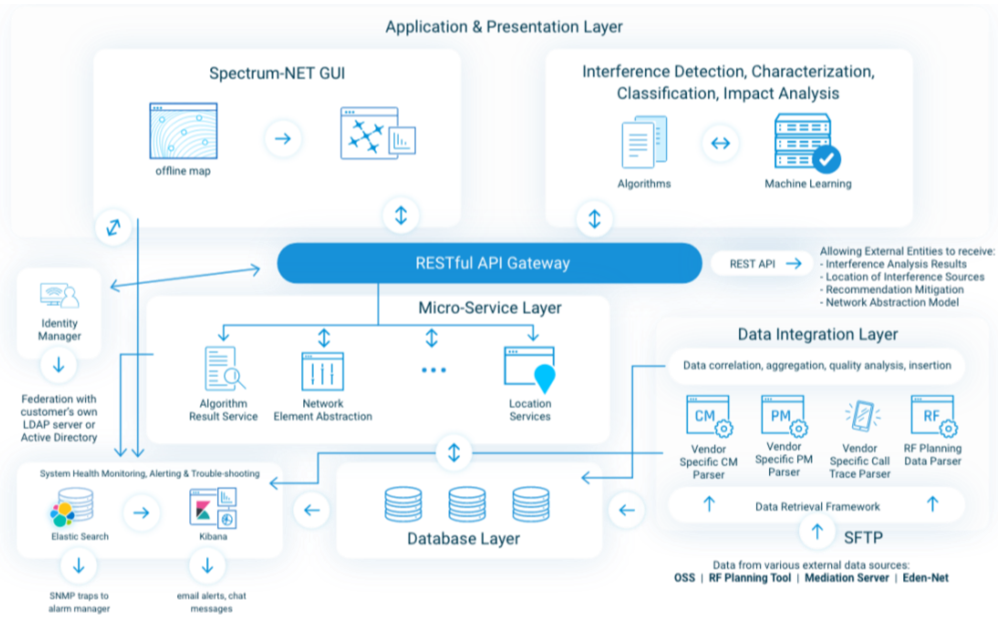


Figure 3 – Spectrum-NET Software Architecture

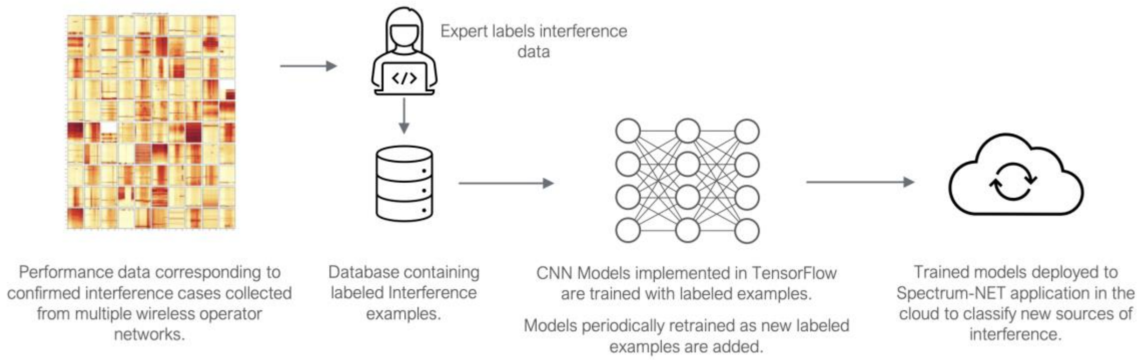
5. CLASSIFICATION OF RF INTERFERENCE USING ML-TRAINED CNN'S

Spectrum-NET ingests PM, CM and topology data and then performs 7 stages of analysis on the interference sources. Updates are captured to interference events on a per reporting period (ROP) basis. For most mobile networks, ROP's are 15 minutes or 1 hour. The results of the analysis are actionable events with key information for addressing the source of the RF interference.

Approximately 7.5% of cells in networks monitored by Spectrum-NET experience severe RF interference, which is defined as interference that has an outsize negative impact on cell performance. Typical examples for LTE would be cell average interference levels above -105dBm/PRB or cell average interference levels above -110dBm/PRB.

Spectrum-NET analyzes interference measurements on a per-PRB basis to provide a spectral-signature of the interference source in the spectral-domain. This spectral-signature aids in determining the type of interference source, the interference power at the cell, and the cells that are impacted by a common interference source.

Spectrum-NET is pre-populated with Deep Convolutional Neural Network (CNN) models that classify interference types using features extracted from the operator network data. These models have been trained with an extensive set of labeled measurement examples from multiple operator environments. As new interference types are identified, additional measurement examples associated with the new interference type are labeled, and the models are periodically re-trained with the new data. The measured accuracy of the CNN models is greater than **95%**.



Operator Networks Analyzed	Labeled Interference Data Samples	Hours of Labeled RF Interference Data	RF Interference Classification Types
50	300,000	7,000,000	16

Figure 4 - ML Model Training and Development.

Spectrum-NET provides Aggregated Interference Events. Each interference event groups together the cells affected by an interference source sharing the same set of characteristics. Figure 5 shows an example of interference seen at multiple cells, which are aggregated into a single event. The aggregator extracts interference power from each cell that is used to find the location of the interference source.

Figure 5 – Example Spectrum-NET RF Interference Aggregation Affecting the T-Mobile U.S. Network

6. CLOSED-LOOP AUTO-MITIGATION OF RF INTERFERENCE

Spectrum-NET automatically mitigates cases of RF interference by pushing changes to cell configuration parameters. These Sense and Maneuver algorithms for determining what parameters to changes and under what conditions to change the parameters are trade secrets of Spectrum Effect. Spectrum-NET can drive these parameter changes directly to the RAN equipment or through a 3rd party configuration management system, SON tool or RAN Intelligent Controller (RIC).

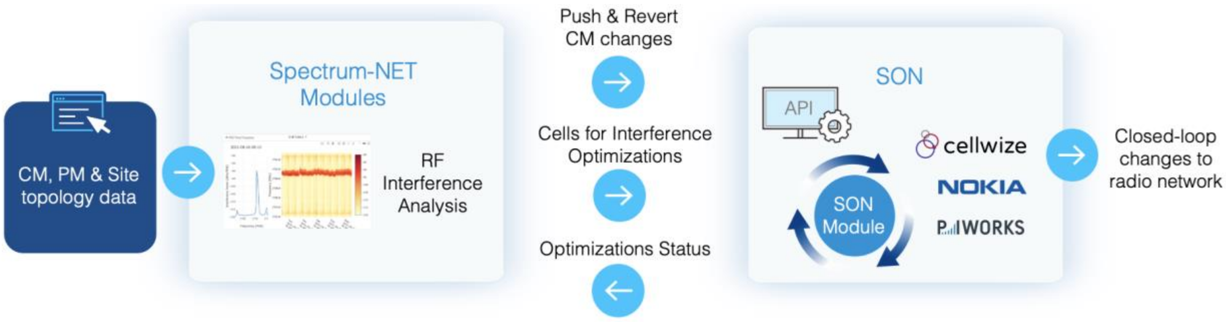


Figure 6 – Closed-Loop Integrations with Operator's SON tool integration.

7. EXTERNAL RF INTERFERENCE DEMYSTIFIED

Spectrum-NET captures and locates external sources of RF interference:

- Accurate identification of which cells are experiencing external interference.
- Characteristics of external RF interference (e.g., time, frequency, intensity) to assist field teams in finding the interference source.
- A list of all cells impacted by the same interference source.
- Assessment of KPI impact from an interference source, which helps operators prioritize interference resolution activities.
- Heatmap that provides the probable location of the interference source.
- Near real-time view of interference cases, which ensures the field team knows if the interference source is still active when they are actively searching for it.

External interference occurs when the source of interference impacting a collection of cells is external to the Radio Access Network (RAN), i.e., not generated within the RAN. Typical sources of external interference include RFID scanners, DECT devices, CATV cable egress, FM radio harmonics, wireless microphones, industrial equipment, bi-directional amplifiers, RF jammers and cross border transmissions. Figure 7 shows examples of signatures of external RF interference learned by Spectrum-NET.

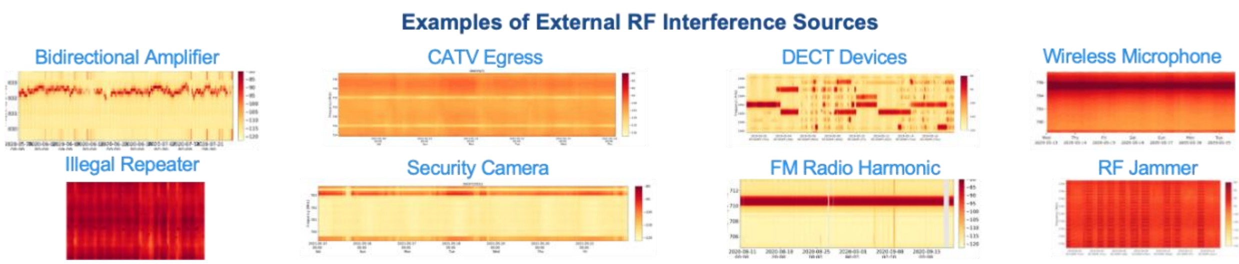


Figure 7 - Examples of External Interference Signatures Learned by Spectrum-NET.

For all identified external interference events, Spectrum-NET provides the locations of external interference sources to expedite the interference hunting process. Spectrum-NET identifies these locations by applying Spectrum Effect's patented Bayesian inference-based locating algorithm to uplink measurement data at the base stations. A heatmap showing the highest probability location of the external interference source in the affected area is generated. Spectrum-NET divides the area around the impacted cells into pixels and uses Bayesian inference to determine the probability of the external interference source being located at each pixel. Detailed antenna information from topology data and terrain information are used to calculate the hypothetical measurement data and provide a reliable and accurate location.

Spectrum-NET interference locating algorithms use both horizontal and vertical antenna radiation pattern information to determine where interference is coming from. Spectrum-NET deployments make use of the Shuttle Radar Topography Mission data when determining the location of interference sources. This is a global dataset that provides terrain elevation information with 30-meter (1 arc-second) resolution. The incorporation of this dataset provides optimal interference location accuracy, especially in hilly environments.

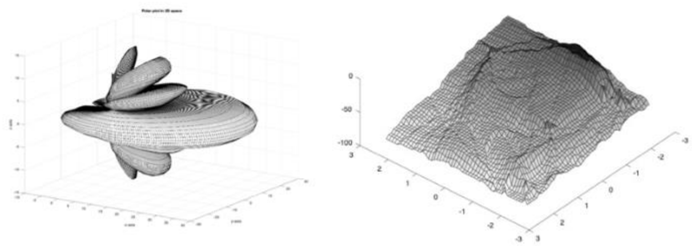


Figure 8 - 3-D Antenna model example and SRTM Data in Spectrum-NET.

By using topographic elevation data, vertical antenna pattern, antenna mechanical tilt and antenna electrical tilt information in conjunction with horizontal antenna pattern information, interference sources are accurately located in all scenarios. For single site interference cases, where interference is seen at cells of only one site, the vertical antenna gain information allows the distance to the interference source to be determined.

Figure 9 shows an example of external interference locating. As outputs of the locating algorithm, Spectrum-NET provides a heatmap showing the probable location of interference source and the search area coordinates where Spectrum-NET recommends that the interference hunting team begins their search.

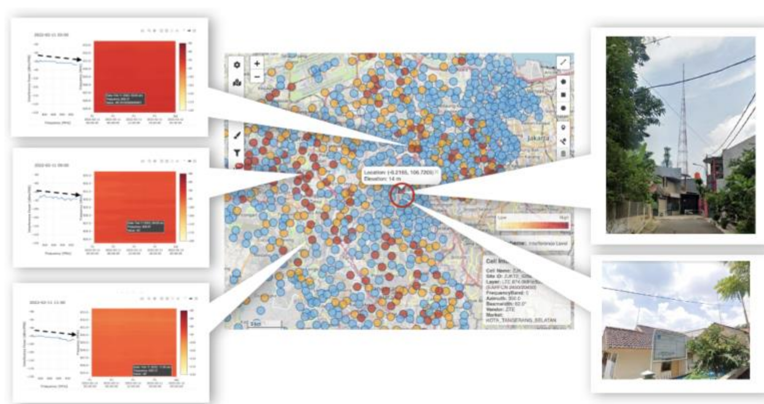


Figure 9 - Spectrum-NET External Interference Locating.

8. PASSIVE INTERMODULATION (PIM) INTERFERENCE DEMYSTIFIED

Spectrum-NET identifies and performs root cause analysis of Passive Intermodulation (PIM) interference:

- Accurate identification of which cells are experiencing PIM.
- Determination of whether the PIM interference source is external or internal, which saves time needed to troubleshoot and resolve cases.
- A list of all cells impacted by the same interference source.

- PIM Spectrograph: an analysis of the frequencies at each site that shows where the potential for PIM exists (IM2 – IM5) and generates a PIM Assessment Score indicating the cell's susceptibility to PIM interference.
- Assessment of KPI impact (e.g., session drop rate, access failure rate, handover failure rate, downlink/uplink throughput and latency) from an interference source, which helps operators prioritize interference resolution activities.
- Near real-time view of interference cases, which helps operators monitor cases over time and confirm if a particular interference source is still active or has been resolved.

PIM interference is caused by electrical nonlinearities present at different positions along the RF signal's path. Downlink transmissions can combine together at these nonlinearities to produce a signal that interferes with uplink frequencies. Since the nonlinearities are 'passive' (meaning they don't require external power), the process is known as Passive Intermodulation (PIM).

The result of the non-linearity is the creation of intermodulation (or IM) frequencies. When two or more signals with different frequencies are present in a non-linear system, signals with other frequencies are created. This process is called intermodulation. The IM frequencies are combinations of sums and differences of the frequencies in the original signals. When the frequencies of an intermodulation signal overlap with the uplink frequencies at a cell site, they can cause PIM interference. Some important attributes of signals created by IM include:

- IM power generally decreases with increasing order.
- IM bandwidth increases with increasing order.
- The number of possible IM signals grows exponentially with increasing IM order.
- Most PIM interference problems are caused by IM signals of up to order 5, although higher order PIM interference has also been found to impact uplink cellular channels.

The deep CNNs used for interference classification have been trained with labeled PIM interference data from many mobile networks. Figure 10 shows an example of a PIM signature and a PIM Spectrograph showing where the potential for PIM exists (IM2 - IM5).

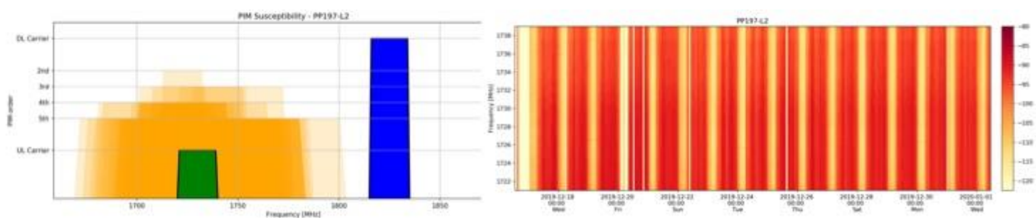


Figure 10 – Example of the Spectrum-NET PIM Interference Signature from Phnom Penh.

Once PIM interference is detected at a cell, Spectrum-NET performs additional analysis to determine whether the source is internal (in cabling or antenna) external (beyond antenna). The PIM nonlinearities can come from "internal" sources between the RF hardware and antenna such as degraded connectors, faulty feeders, or corroded RF cabling. The PIM nonlinearities can also come from "external" sources which are located near the antennas at a site. These sources can include rusty/corroded bolts or joints and metallic plates.

9. RAN GENERATED INTERFERENCE (RGI) DEMYSTIFIED

Spectrum-NET captures and performs root cause analysis of RAN Generated Interference (RGI): Accurate identification of which cells are experiencing RGI.

- Determination of the root cause of RGI.
- Assessment of KPI impact (e.g., session drop rate, access failure rate, handover failure rate, downlink/uplink throughput and latency) from an interference source, which helps operators prioritize interference resolution activities.
- Near real-time view of interference cases, which helps operators monitor cases over time and confirm if a particular interference source is still active or has been resolved.

RGI refers to UL co-channel interference generated by UE's in neighboring cells. Spectrum-NET characterizes RGI interference by time, frequency and intensity and aggregates cells affected by the same source of the uplink RGI into clusters. Figure 11 shows an example RAN Generate Interference signature.

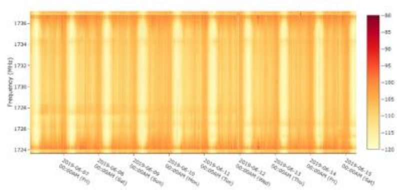


Figure 11 – Example RGI Signature.

Spectrum-NET determines the root cause of the RGI such as overshooting cells, insufficient separation between antennas, imbalanced traffic load among layers, or misconfigured parameters, which helps operators identify the right course of action to take to mitigate the interference. Spectrum-NET performs cell utilization analysis on RGI clusters and measures the KPI impact from the RGI on each of the cells in the affected clusters to help identify which cells are most important to resolve first. Figure 12 shows the most common cause of RGI.

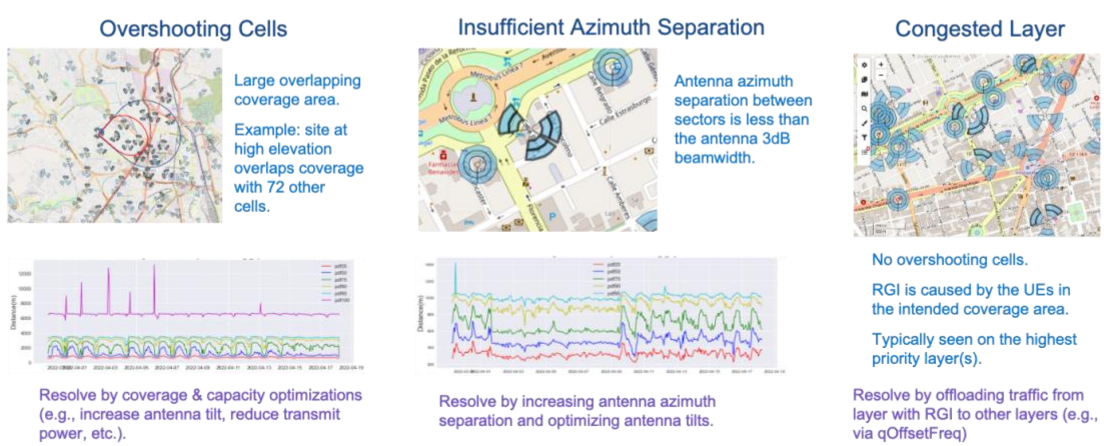


Figure 12 – Most Common Cause of RGI

10. TROPHOSPHERIC DUCTING INTERFERENCE DEMYSTIFIED

Spectrum-NET captures RF interference caused by tropospheric ducting and determines the source of the RF interference:

- Accurate identification of which cells are experiencing ducting propagated interference.
- Identification of when ducting episodes begin and end.
- Near real-time view of interference cases, which helps operators monitor ducting episodes as they occur.
- Assessment of KPI impact from an interference source, which helps operators prioritize interference resolution activities.
- Determination of aggressor cells (i.e., the cells causing the TDD self-interference) and the direction and location of sources of the interference carried during the periods of tropospheric ducting.
- Creation of a record for each ducting episode, including information about the start/end time, impacted cells, etc. for each episode.

Tropospheric ducting is a large-scale physical phenomenon observed under specific weather conditions. During a tropospheric ducting event, differences in air temperature and moisture content produce a layered structure in the atmosphere which acts as a waveguide, allowing RF signals to propagate over long distances and causing uplink interference in cells hundreds of kilometers away from the interference source.

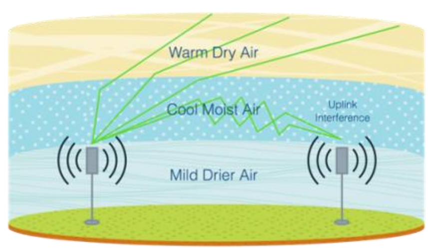


Figure 13 – Weather Conditions Enabling Tropospheric Ducting.

5G NR and TDD-LTE systems are particularly susceptible to ducting interference when the guard period between downlink transmission and uplink transmission is not large enough. Downlink signals from distant cells, even from other neighbor markets, can propagate more than 200km and interfere with uplink signals, resulting in TDD self-interference due to ducting. For both FDD and TDD networks, ducting can lead to interference on the uplink of cells within a mobile network from cross border transmissions.

Spectrum-NET continuously analyzes ingested PM counters to dynamically identify when interference carried by tropospheric ducting starts and ends. Spectrum-NET automatically determines the aggressor cells (i.e., the cells causing the TDD self-interference). The Spectrum-NET interference location feature is used to determine the direction and location of sources of the interference carried during the periods of tropospheric ducting.

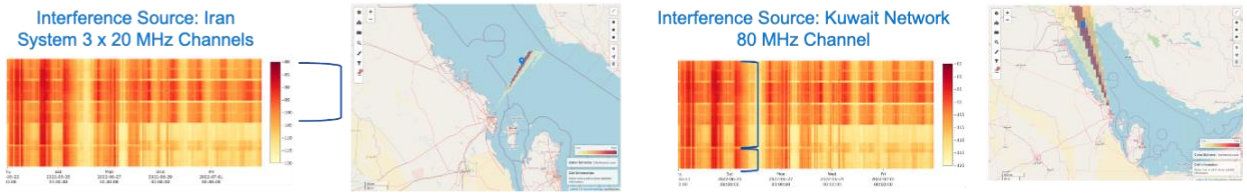


Figure 14 - Tropospheric Ducting (Examples of n78 Band in Saudi Arabia).

Since tropospheric ducting is heavily influenced by weather conditions, occurrences of tropospheric ducting usually vary seasonally. Figure 15 illustrates the changes to the number of cells experiencing severe interference from TDD self-interference via tropospheric ducting in US cities during December – March.

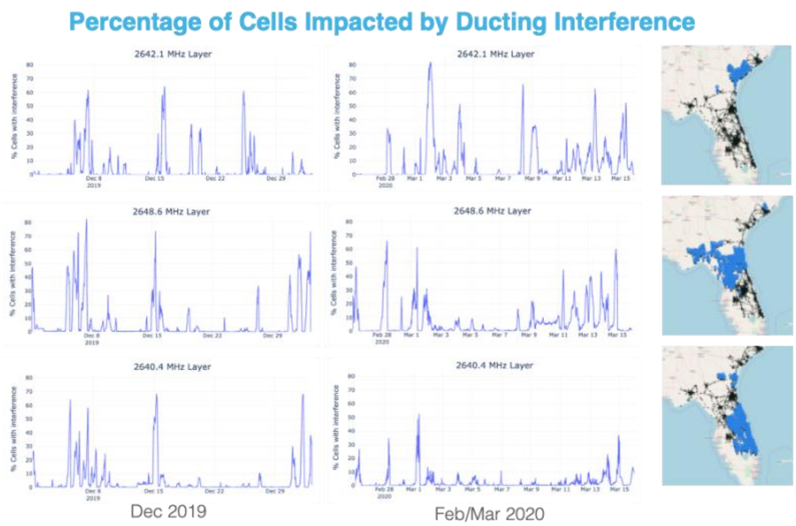


Figure 15 –Tropospheric Ducting Patterns Over Time (example from Florida).

Upon detection of ducting interference, parameter reconfiguration can be performed on dominant aggressor cells to mitigate the impact of ducting interference.

Tropospheric ducting can also lead to cross border RF interference for TDD and FDD cells. Spectrum-NET detects when these ducting events occur, identifies the victim cells, captures the frequency-time signature of the RF interference and locates the direction and area of the cross-border interference source(s).

Figure 16 shows the Spectrum-NET PRB chart of RF interference experienced in Al Ain City, UAE, coming from UHF TV transmissions in Iran during periods of tropospheric ducting. In this example, there are two separate TV transmitters/interference sources: transmissions of UHF TV channels 66 and 67. Figure 17 shows the location of the cross-border sources determined by Spectrum-NET as well as the seasonal variation in the amount of ducting interference from July through September.

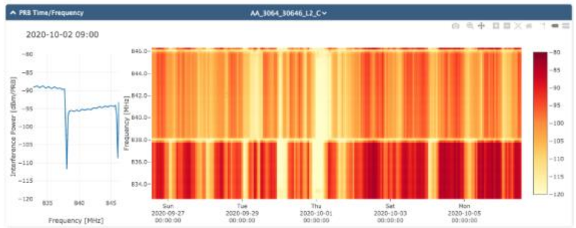


Figure 16 – PRB Chart Showing Cross Border RF Interference During Ducting Example in Al Ain City.

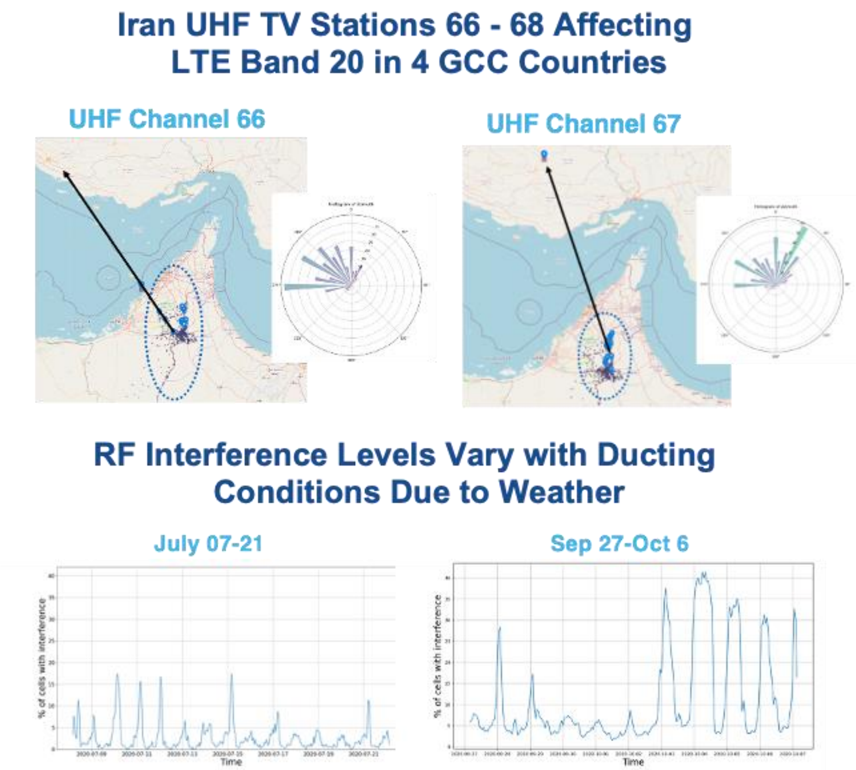


Figure 17 – Cross Border RF Interference During Ducting Example in Al Ain City from Iran.

11. REGULATOR PORTAL

The Spectrum-NET Regulator Portal helps operators work more easily with regulators on managing external interference events that require regulator support to resolve.

Once Spectrum-NET detects external sources of interference, the operator can select which specific events to share with their local regulator for investigation and resolution as shown in Figure 18.

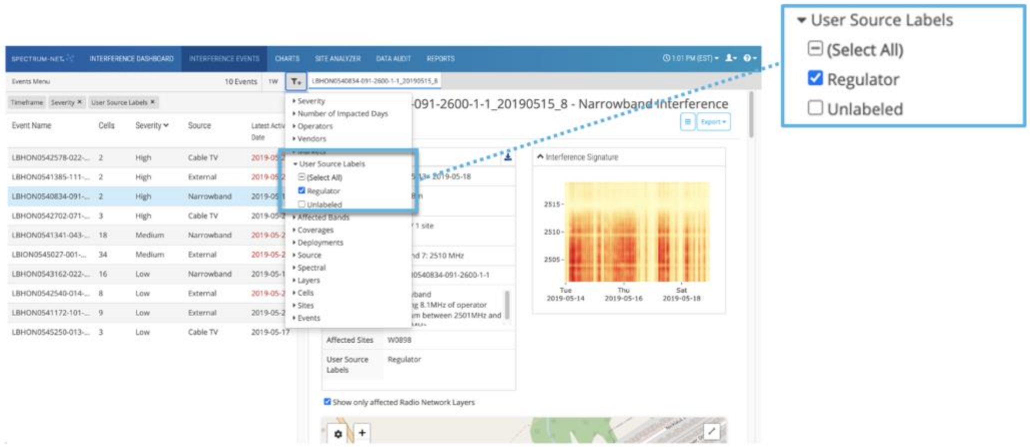


Figure 18 - Operator selects events for collaboration with the regulator.

The regulator logs into Spectrum-NET through the Regulator Portal, which limits their view to just the events selected by the operator for viewing. The regulator can export interference characteristics of the events to assist in investigating each interference source and update the status of each event.

Both parties can add comments and attachments to interference events to capture the results of any investigation or observations made by in-field teams (e.g., spectrum analyzer screenshots, photos of interference sources).

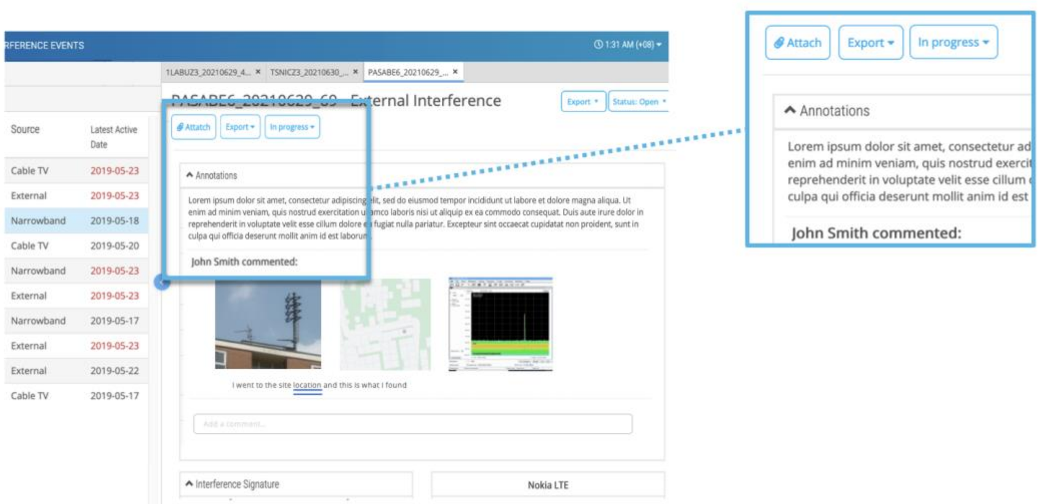


Figure 19 - Regulator or operator can provide commentary by event.

12. USER INTERFACE AND REPORT GENERATION

The Spectrum-NET user interface makes it easy to view interference events by providing summary and detailed interference view tabs. This allows for fast navigation of interference event details. User sessions are automatically saved. The mapping views provide normal, terrain and satellite view map layers. Figure 20, Figure 21 and Figure 22 show examples of the Spectrum-NET UI.

The Spectrum-NET UI provides a dashboard view of the RF interference environment within the mobile network. Users can view the distribution of events by time, source, technology, RF band and RF layer. Users can sort, filter and select events by different criteria including severity, number of cells, source type, etc. The Spectrum-NET UI allows users to select each interference event for an in-depth view. The detailed view includes the interference frequency/temporal characteristics, location, classification source, impacted cell/sites, performance charts, additional information specific to the interference type and the KPI impact of the interference event.

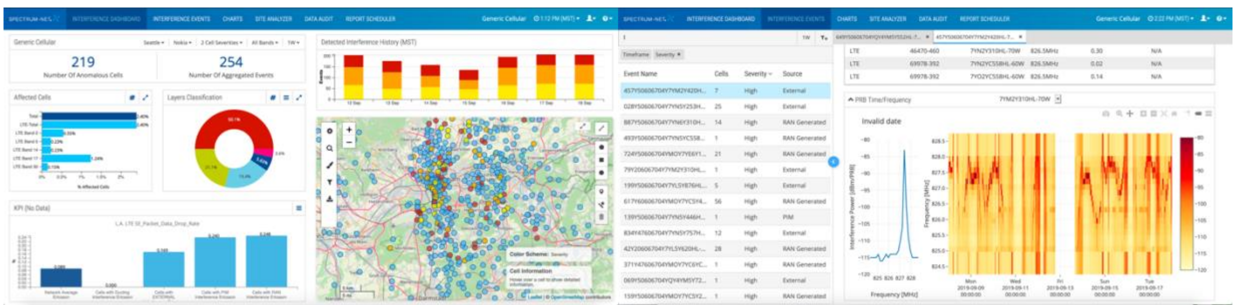


Figure 20 – Spectrum-NET Interference Dashboard and Example External Interference Event

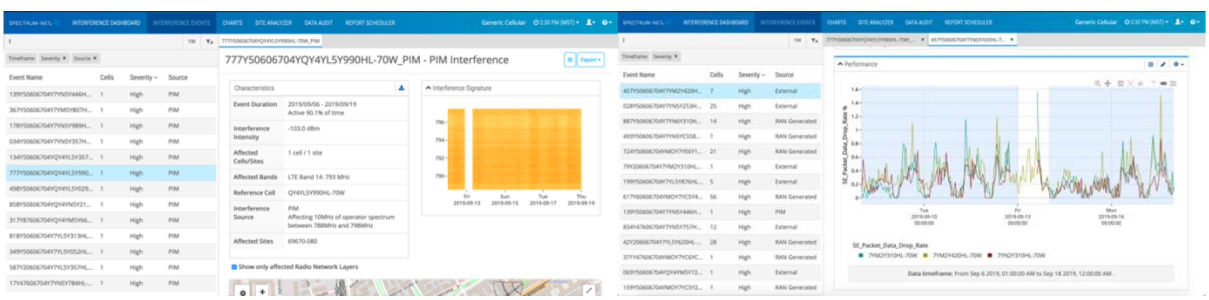


Figure 21 – Spectrum-NET Example PIM Interference Event and Performance Chart

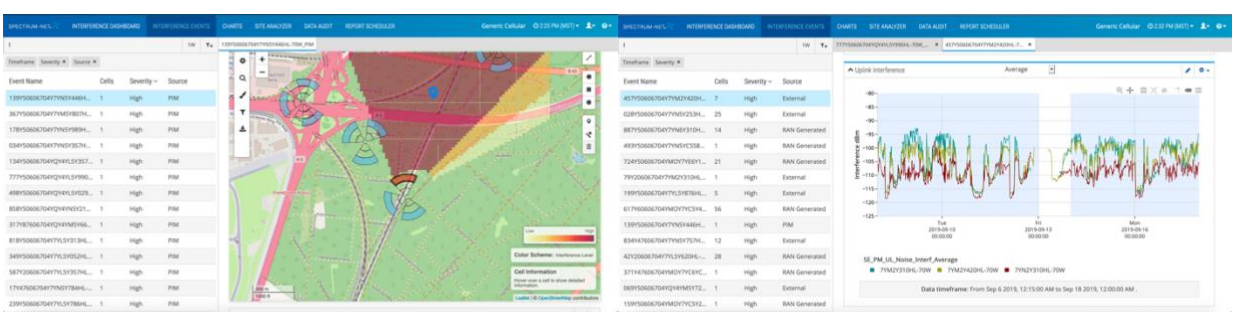


Figure 22 – Spectrum-NET Interference Locating and Average Interference Chart

Report generation is available within Spectrum-NET and enables convenient exporting of dashboard views and detailed event views manually or on a scheduled basis.

To aid in-field interference hunting, a spectrum analyzer configuration file may be exported from Spectrum-NET for each interference event. These files are loaded into compatible interference hunting tools, which are then automatically configured to the correct frequency for interference hunting. The export includes information about the interference characteristics, allowing guidelines to be displayed on the spectrum analyzer screen showing the extent of the interference signals. This makes it easier for field personnel to identify if interference seen in the field is at the same frequency as reported by Spectrum-NET.