



Why spectrum monitoring is critical to ensure safety & success at major events

USE CASE: 2022 FIFA WORLD CUP IN QATAR

SILVUS
TECHNOLOGIES
a Motorola Solutions Company

RFeye®



TABLE OF CONTENTS

Introduction to spectrum monitoring and management at a major event	3
Wireless technology at the 2022 FIFA World Cup in Qatar	4
Equipment setup	5
Pre-event spectral planning	6
Real-time spectrum monitoring during the event	9
Redeploy systems post-event	11
Conclusion	12





INTRODUCTION TO SPECTRUM MONITORING & MANAGEMENT AT A MAJOR EVENT

There is no bigger event than the World Cup—the biggest of all ‘major events.’ To run effectively, a World Cup requires the participation and coordination of many different parties, including national regulators, government departments, emergency services, telecommunications operators, international public authorities, national and international broadcasters, and fans.

Fortunately, spectrum demands can be accurately forecasted, and frequency allocations arranged long before kick-off. However, delivering a safe and successful event that leverages the latest technologies, ensures reliable communications, and provides seamless connectivity to attending fans and viewers worldwide, requires, as the ITU states:

"Adequate spectrum planning, licensing, spectrum monitoring, inspection of radio stations, and processing of radio interference...Moreover, technical equipment limitations and last-minute license applications require rapid and, in particular, flexible on-site frequency management during the event."

This guide is aimed at national spectrum regulators planning their spectrum management strategy for a major event. To demonstrate Silvus Technologies’ capabilities, we use the 2022 FIFA World Cup in Qatar as a use case—an event that was highly dependent on wireless technology to deliver a world-class experience for fans in attendance and watching around the world.

The following sections outline how national regulators could deploy sensors at each stadium and manage the spectrum across all stadiums from a remote command center. They address three levels of spectrum monitoring and management:

- Macro: broad visibility across all stadiums
- Meso: visibility in the surrounding area outside each stadium
- Micro: visibility inside each stadium

The strategy uses CRFS’ RFeye ecosystem during three stages: pre-event, during the event, and post-event. This structure ensures authorities can conduct baseline spectrum management before the event, detect interference and ensure reliable communications during the event, and repurpose the technology to ensure the successful delivery of future events.

SPECTRUM DEMANDS

- Police
- Ambulance
- Event security
- Broadcasting
- Wireless microphones
- Cameras
- RLANs
- IoT devices
- Wi-Fi
- Drones
- AR/VR technology

WIRELESS TECHNOLOGY AT THE 2022 FIFA WORLD CUP IN QATAR

Proactively monitoring the electromagnetic spectrum using superheterodyne RF sensors can help formulate a robust spectrum management plan.

At the 2022 FIFA World Cup in Qatar, five billion people watched televised broadcasts, 3.4 million people attended live games, and 1.8 million watched live broadcasts of the games. At every match, there was an average of 42 standard cameras, plus drone cameras, spider cameras, and helicopter-mounted cameras. Spectators watching live games could use the FIFA+ Stadium Experience app, which includes features such as live augmented-reality overlay of stats, different camera angles, and video assistant referee (VAR) replays.

A country-wide rollout of 5G (with over 5,000 cells), assisted by TETRA and Wi-Fi, provided the network for the digital technologies used at the event. Across the stadiums, there were 8,466 multibeam antennas and over 310 miles of RF cable to assist technological innovations such as Internet of Things (IoT) technology, virtual reality (VR), and augmented reality (AR). To ensure security, the authorities deployed more than 15,000 security cameras.

To broadcast, plan, and execute logistical spectrum operations at the World Cup, the Communications Regulatory Authority (CRA) issued over 25,000 authorizations for radio applications and equipment—an unprecedented number in the tournament’s history.

These licenses allowed the Fédération Internationale de Football Association (FIFA), FIFA contractors, FIFA commercial affiliates, and broadcasters to use RF-emitting equipment at official World Cup venues.

The 2022 World Cup used a wide range of radio applications and was heavily reliant on advanced wireless technologies concentrated within a limited area. The Communications Regulatory Authority (CRA), the entity responsible authority for managing, assigning, licensing, and monitoring the use of the radio spectrum in the State of Qatar, decided not to allow any radio equipment to be used in the official venues unless it had previously been tested, tagged, and registered by the CRA.



EQUIPMENT SETUP

Goal: Create the infrastructure to monitor the spectrum at a World Cup



Step 1 – Establish a command center

The first step in effective spectrum monitoring at a major event is to establish a central command center, either as a single, fixed location or as a remotely distributed setup. From the command center, spectrum managers can monitor and share the data collected by RF sensors (RFeye Nodes) deployed at each stadium.

Although it is often practical to place the command center near the main stadium, spectrum managers can also be dispersed across a country or even globally; as long as they have a network connection, they can be located anywhere.

During the World Cup in Qatar—a small peninsula 160 km (99 miles) long and 90 km (56 miles) wide at its widest point—a central office served as the command center. However, remote monitoring capability will be invaluable for the next two World Cups, both to be held across three countries.

Step 2 – Deploy RF sensors at each stadium

Given football stadiums' rectangular shape, sensors could be placed at each of the four corners. While conventional theory suggests that a 'Y' configuration is optimal geometry for RF sensor deployment, placing a sensor in the middle of the pitch is not practical. (However, this shape could be achieved with a tethered drone in the center of the pitch.) Additionally, since interference is unlikely to come from the center of the stadium, using a rectangular layout will not compromise the detection of RF interference or jamming.

RFeye Nodes can either be placed in fixed positions in outdoor kits, which have IP66 ingress protection, or flexibly deployed in RFeye Stormcases, which offer mobile spectrum monitoring in a ruggedized unit.



PRE-EVENT SPECTRAL PLANNING

Goal: Conduct preventative spectrum monitoring activities

Software training

CRFS offers comprehensive software training (either onsite or virtual) aimed at both expert and non-expert users. We understand that national regulators are often operating with a lean team; therefore, the focus of training courses is to empower staff to automate as much spectrum monitoring as possible.

RFeye Site is a real-time spectrum monitoring and geolocation toolkit containing all the essential functionality for full spectrum operations. It is packed with advanced functionalities that are ideal for RF experts. Multi-mission capability enables multiple spectrum monitoring and geolocation tasks to be run simultaneously. The software can also be customised to application requirements and includes optional plugins

RFeye Mission Manager is an automated spectrum management and near-time incident reporting software toolset. It is designed for non-RF experts, and the training focuses on automating tasks, missions, alerts and reports.

Pre-event simulation exercises

Modeling expected spectrum conditions during a World Cup and conducting simulation exercises can help teams hone their spectrum monitoring skills. Pre-event exercises could also involve emergency planning and rehearsals, including interrupted signal and satcom for the broadcasting stations.

Using RFeye Site's training capabilities, instructors can configure simulation transmitters with any power level and transmit frequency. Various transmitter modes can be established, including modulated signals with bandwidth control, pulsed on/off times, pulsed words with repeat intervals, and frequency hopping. Instructors can also manually set bearings and locations or import them from a GPX file.

Based on these parameters, teams can practice identifying signals and applying the most appropriate geolocation method (PoA, AoA, 2D TDoA, or 3D TDoA) for the mission. Once a signal is located, teams can establish a workflow to coordinate their planned response to potential interference.

Saving a mask serves as the baseline, setting the upper limits for frequency ranges and power levels in future monitoring. It can be loaded into the RFeye Mission Manager software for continuous background monitoring. If the mask is broken, the software notifies users with an instant message, alerting them that a signal has exceeded its allowed frequency or power levels, potentially causing interference.

RFeye Mission Manager can be configured to automatically trigger a geolocation when a mask is broken. Users can then use RFeye Site to refine the result in real time, checking if the signal is still active, and attempting geolocation techniques to pinpoint a precise location.

Establish a spectral baseline

Establishing a spectral baseline before a World Cup enables proactive spectrum management throughout the event. By recording the spectrum at each stadium in advance, spectrum managers can identify standard frequency patterns, detect potential interference, and monitor for unauthorized signals during the tournament. If any signals of interest are found during the recording, they can be detected, geolocated, and personnel can be dispatched to investigate the signals.

There were eight stadiums at the 2022 World Cup in Qatar.

- Al Bayt Stadium
- Lusail Stadium
- Ahmad bin Ali Stadium
- Education City Stadium
- Khalifa International Stadium
- Al Thumama Stadium
- Stadium 974
- Al Janoub Stadium

To establish a baseline at each stadium, an RF expert should run RFeye Site in 'learn mode' for several hours at a representative period. In the baseline period, it is crucial to include frequency ranges used by local broadcasters, communication systems, and emergency services.

This activity helps identify regular spectrum activity and allows the user to create a mask, which sits just above the spectral envelope and outlines the frequency range and power levels within and around each stadium.

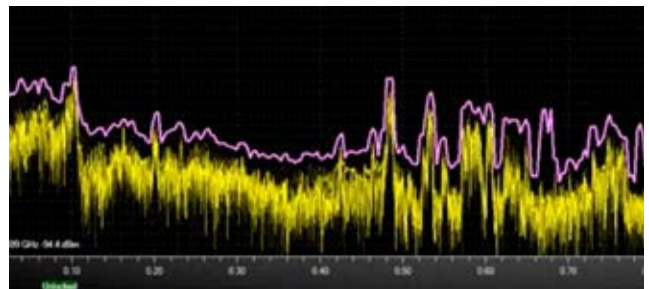
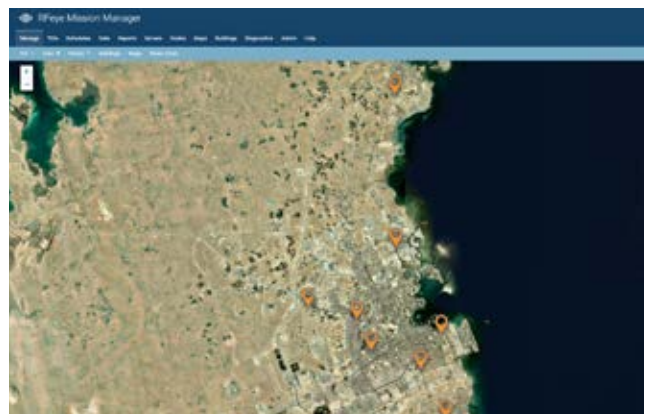


Image 1: Spectral mask (in pink) hovering above the spectral envelope



Images 2 and 3: Locations of the eight World Cup stadiums in Qatar in RFeye Mission Manager

When a spectral baseline has been established, users can pre-schedule tasks and populate events for an entire event in RFeye Mission Manager's calendar. These events can be edited and adjusted on-the-fly as required.

Frequency allocation and planning

At major events, the large number of temporary frequency allocations makes it nearly impossible for spectrum managers to remember every assigned band. Therefore, a compact visual overview of all license holders’ frequency bands and power levels is essential for efficient spectrum management and compliance.

CRFS’ frequency planning table provides a clear view of each authorized license, their assigned location (if known), frequency, bandwidth, and description of the authorized transmitter. Users can easily navigate the otherwise congested spectrum by selecting the allocation in the chart.

This tool should be set up before the World Cup begins as it provides broad spectrum management capabilities; however, it remains useful throughout the tournament. If used in combination with a mask (shown in pink above the spectrum), spectrum managers receive an automatic alert if the mask is broken. They can then easily see the offending broadcaster and immediately contact them to make signal adjustments.

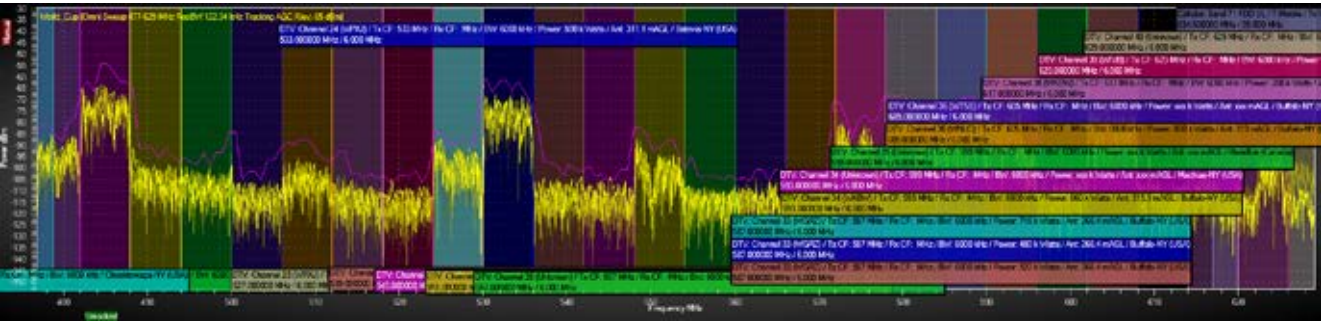
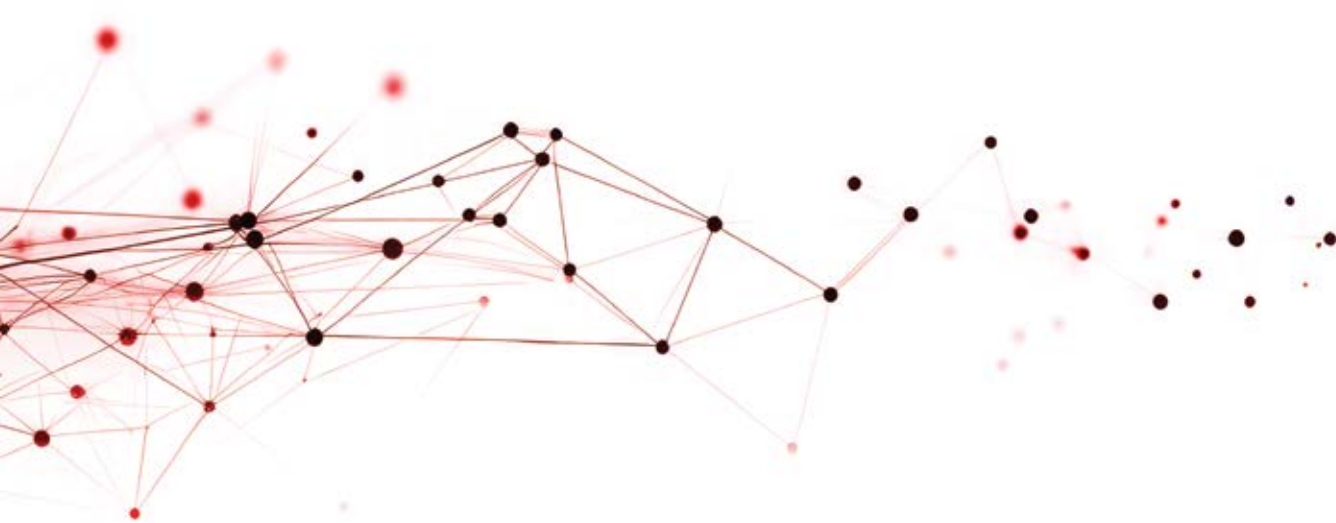


Image 4: Frequency allocation table showing all license holders in a given band.



REAL-TIME SPECTRUM MONITORING DURING THE EVENT

Goal: Ensure interference-free communication for broadcasters, security teams, emergency services, mobile networks, and spectators.

During the games, a combination of forensic real-time spectrum monitoring and automated spectrum tasks will help ensure national regulators fulfill their objectives—such as keeping emergency services’ communication equipment and broadcasters’ wireless devices free from interference.

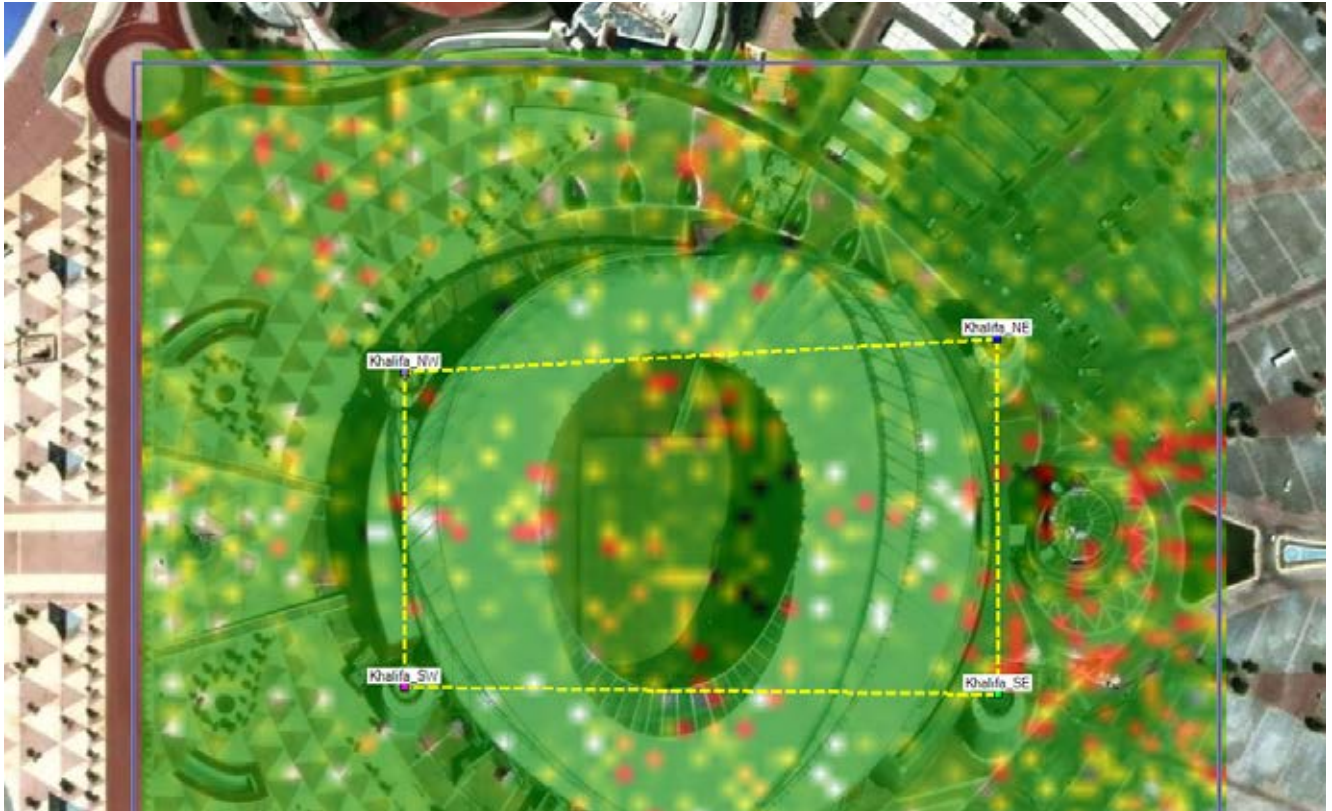
To do this, spectrum managers must monitor the spectrum at the macro, meso, and micro levels. At the macro level, they need to maintain an overview of the spectrum usage across all eight stadiums as there may be concurrent games. However, they also need a continuous understanding of the spectrum in the close vicinity of each stadium (the meso level) and inside each stadium (the micro level).

RF experts can use RFeye Site to monitor the spectrum in real-time, hunting for unauthorized signals inside and around the stadiums and detecting conflicts or potential violations, such as push-to-talk radios inside a stadium. When unauthorized signals are identified, the operator can perform geolocation using the most appropriate method (AoA, PoA, TDoA, 3D TDoA) or a hybrid approach.

In addition to real-time monitoring, the software allows users to conduct spectrum sweeps, I/Q captures, and power, occupancy, bandwidth, and frequency deviation measurements. Users can also visualize the spectrum using interactive charts, maps, and graphs. The software’s multi-mission capability allows multiple spectrum monitoring and geolocation tasks to run simultaneously and can be customized with optional plugins to fit specific user requirements.



Images 5 and 6: Views of all eight stadiums in RFeye Site



↑↑ Images 7: Heatmap of Khalifa Stadium showing RFeye Site geolocation coverage and accuracy over the stadium (Green depicts best-case accuracy (10 m), while red indicates worst-case accuracy (>1km).

For automation, predefined missions created by RF experts in RFeye Site can be loaded into RFeye Mission Manager to run automatically. For instance, if a mask is broken, teams on the ground receive an automated alert requiring immediate investigation. Users can also pre-configure these missions to automatically trigger a geolocation workflow.

Using real-time and automated monitoring software, the spectrum command center can inform engineers on the ground of issues requiring further investigation. Situations could range from interference caused by equipment in a broadcaster's van to an individual using a push-to-talk radio inside a stadium.

Spectrum monitoring with lean teams

As national regulators often only deploy small teams at major events, these teams must rely on technology to ensure a safe and successful event.

Through RFeye Mission Manager, automation is at the heart of the RFeye ecosystem—empowering small teams to complete the tasks that would have traditionally required larger, expert teams.

Automated systems are scalable as they can easily adapt to growing spectrum demands. Moreover, they allow regulators to manage potential issues proactively rather than resort to reactive problem-solving. Multiple sites can be monitored continuously from one central location by a small team that receives real-time alerts of potential issues.

REDEPLOY SYSTEMS POST-EVENT

Goal: Repurpose World Cup equipment for general regulatory activities or other major events.

Economically and reputationally, a World Cup is a high-stakes venture. But it only lasts about a month. Therefore, national regulators need to be sure that their spectrum monitoring hardware and software can be easily redeployed and repurposed for routine regulatory activities as well as other international, political, and sporting events.

Post-World Cup, national regulators can leverage CRFS' RFeye ecosystem for many tasks, including:

- ITU-compliant spectrum monitoring
- Frequency allocation and license holders
- Spectrum occupancy measurements
- Identifying new ways to monetize the spectrum
- OPEX and CAPEX challenges
- Basic spectrum sweeps
- Advanced signal classification
- Real-time geolocation of signals of interest

Additionally, the setup used for major events can be enhanced with RFeye DeepView, a forensic signal analysis software. This tool enables rapid detection of anomalies, analysis of known and unknown emitters, and processing of signals of interest.

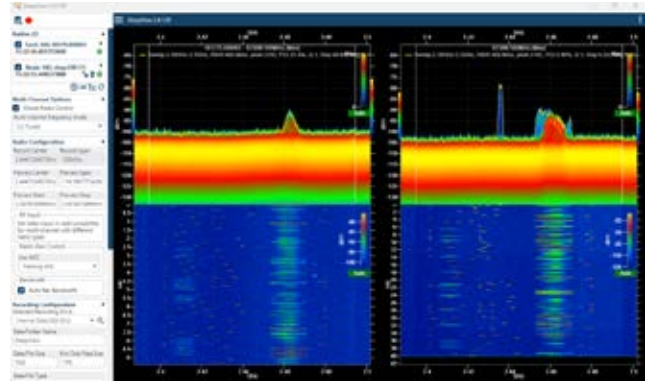
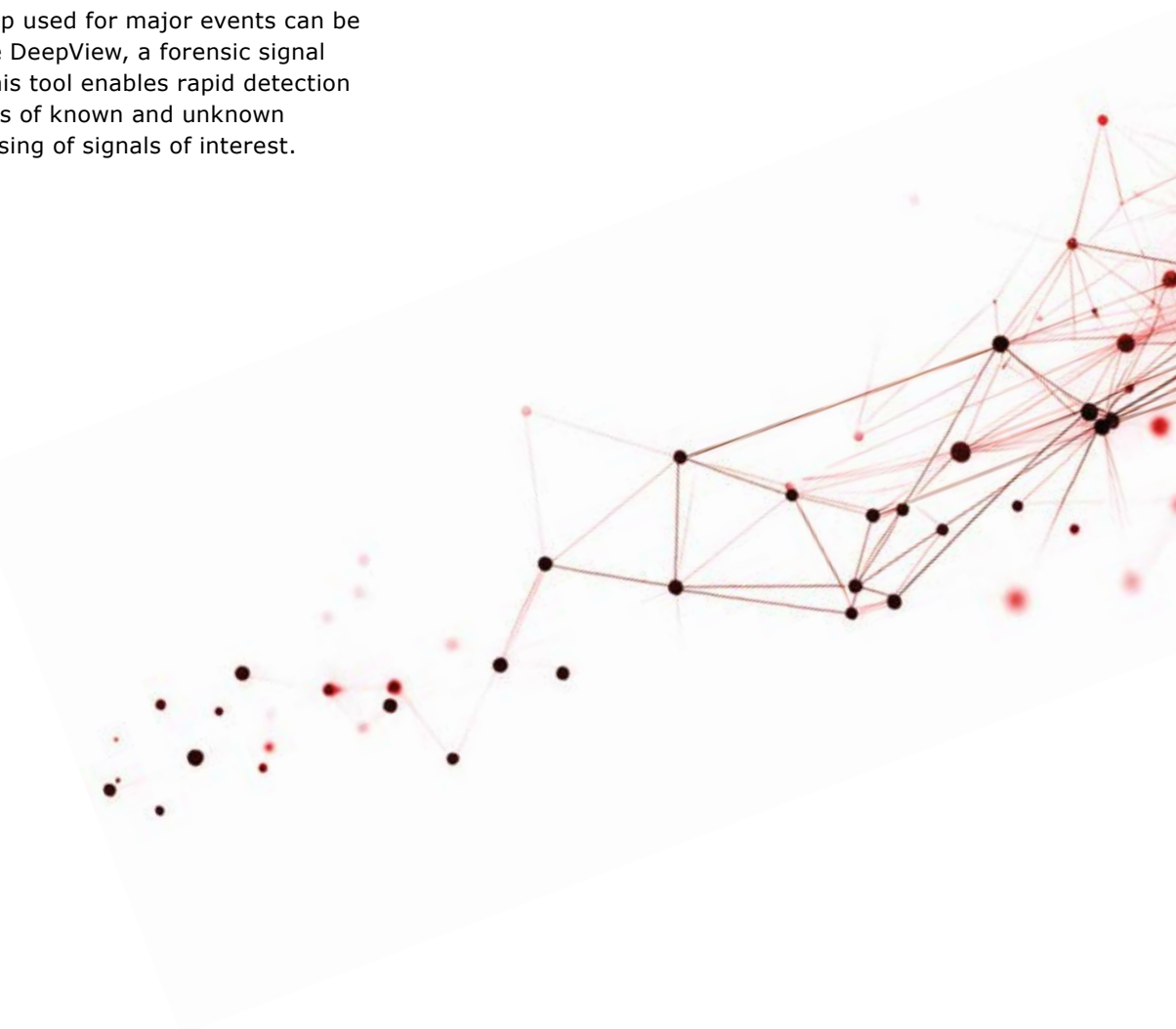


Image 8: RFeye DeepView 2.4 shows live spectrum from a Node and a SenS Portable



CONCLUSION

Effective spectrum monitoring is essential for managing communications, ensuring security, and delivering a world-class experience during major events like the World Cup.

By implementing a well-planned structured strategy—including pre-event training, planning, and simulation and real-time and automated monitoring during the event—national regulators can address the unique challenges of major events, ensuring their safety and success with only a small team.

This strategy increases the chances of detecting issues before the event and allows for swift identification and resolution of problems during the event itself. CRFS' RFeye ecosystem enables regulators to take a proactive approach in three key areas: equipment testing, spectrum monitoring, and spectrum management.

To support national regulators, CRFS offers training for all engineer levels—from the trainee operator to the experienced RF engineer. Additionally, the company provides on-site support, which is invaluable given the challenge of staffing large events like the World Cup.

This document describes a theoretical deployment at the 2022 World Cup. However, CRFS has a proven track record of collaborating with regulators to ensure safety and smooth operations at major global events, including the 2024 Paris Olympics and the World Cup in Rio de Janeiro.



DEPLOYMENT STORIES



BUILDING AN RF MONITORING NETWORK ACROSS FRANCE

How ANFR chose a long-term solution for spectrum monitoring & emerging tech while ensuring safety during major sporting events



MANAGING SPECTRUM AT THE WORLD EXPO IN DUBAI

How the TDRA ensured seamless communication with an RF network that endured temperatures above 45°C



SPECTRUM MONITORING & MANAGEMENT AT THE RIO SUMMER OLYMPICS

How the Brazilian National Telecoms Agency used a remote distributed network at the world's biggest sporting event

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Silvus Technologies, a Motorola Solutions company, builds mission-critical capabilities that enable defense and security organizations to understand the electromagnetic environment, maneuver through the spectrum, and maintain an operational advantage in contested conditions. Through an interoperable ecosystem of industry-leading RFeye™ sensors, resilient tactical communications, and advanced electronic warfare capabilities, Silvus extends SIGINT to dismounted operators and uncrewed platforms—empowering forces to sense threats, connect forces, and command the spectrum. Together, these capabilities deliver the situational awareness and decision advantage needed to achieve spectrum superiority.



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