

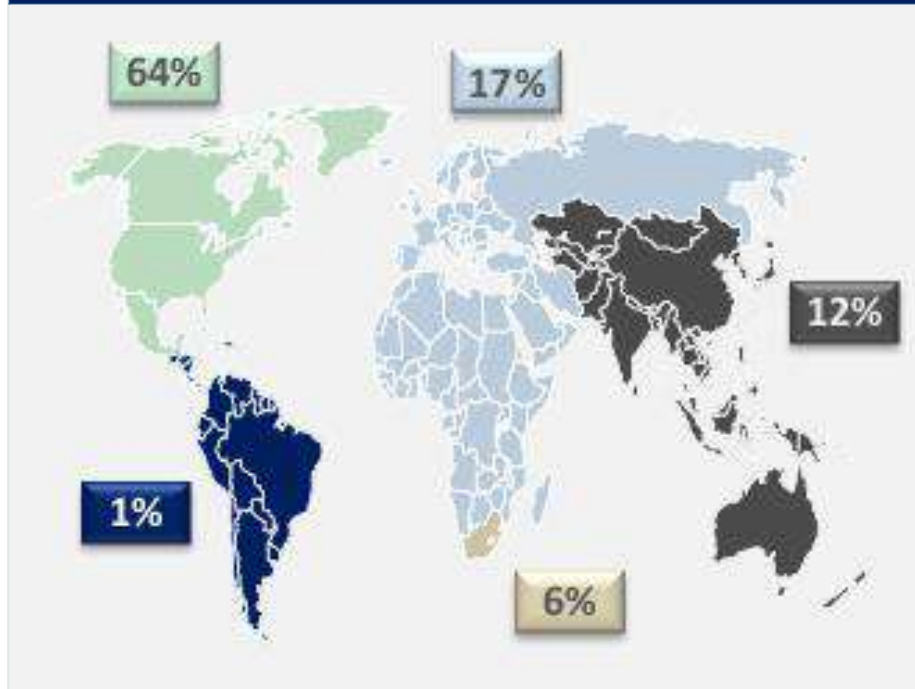
# TCI Spectrum Monitoring & Management Solutions



*A global source for spectrum expertise*



## Revenue by Region



## Key Information

- Headquartered in Charlotte, NC
- A leading supplier of:
  - Detection & Measurement Systems
  - HVAC Products, and
  - Power Equipment
- ~\$1.6B of revenue
- ~6,000 employees
- NYSE Ticker: [SPXC](#)

## 50 Years' RF Spectrum Experience



- RF Design and System Integration
- Digital Signal Processing
- Software Development
- Signal Detection & Characterization
- Direction Finding / Geolocation

## Key Information

- Headquartered in Fremont, California, USA
- Turnkey Solutions for:
  - Spectrum Monitoring & Management
  - Communications Intelligence (COMINT)
  - Broadcast and Communications Antennas
- Installations in more than 100 countries

## Total Lifecycle Support

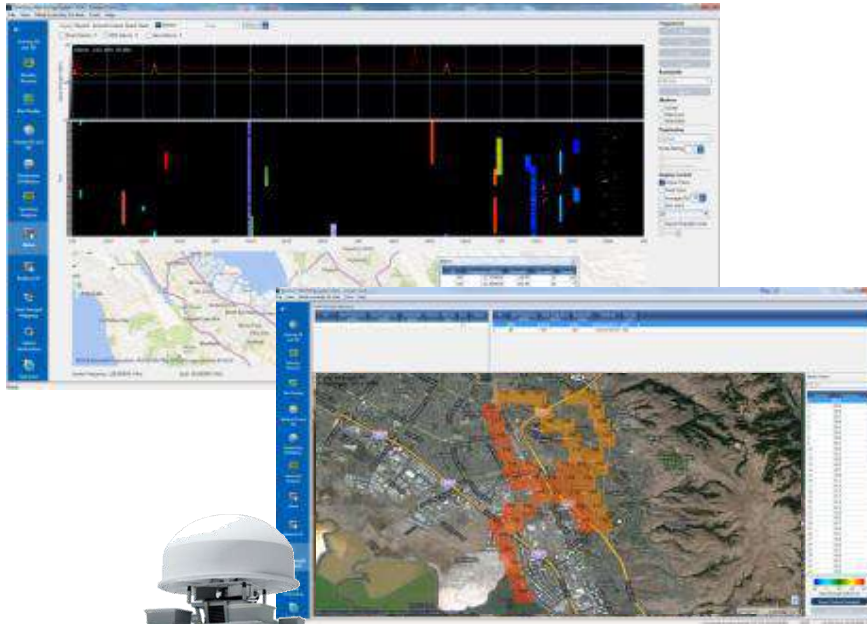


- Design
- Manufacture
- Deployment
- Support

## Discriminators

- Complete Spectrum Monitoring & Management Solutions
- Continuous product improvements
- Solutions that evolve with spectrum complexity
- Global customer support
- Backwards compatibility
- Minimized total lifecycle cost

## Spectrum Monitoring Solutions



## Key Features

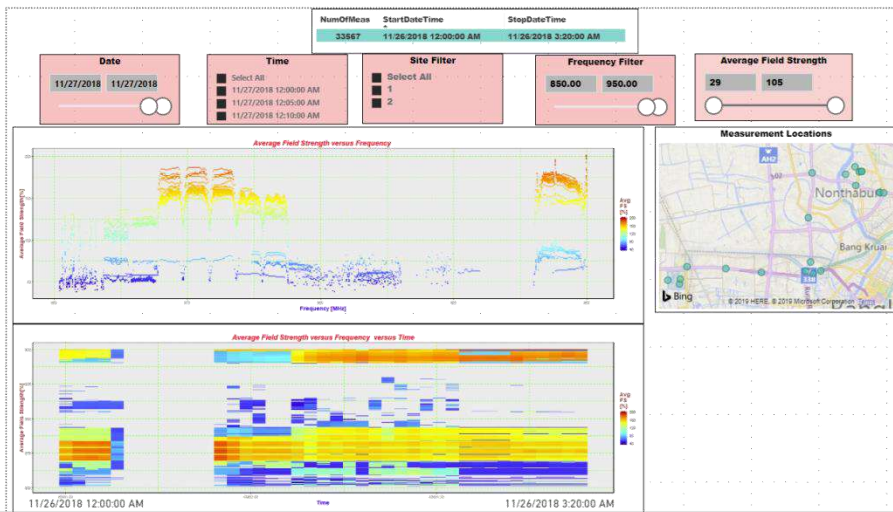
- Fully Integrated ITU Compliant Solutions
- LF, HF, VHF, UHF & SHF Solutions (7 kHz to 40+ GHz)
- AOA, TDOA & Hybrid Direction Finding / Geolocation
- Scheduled / Automated Monitoring; Automatic Violation Detection; Spectrum Occupancy
- Complete Management



## Applications

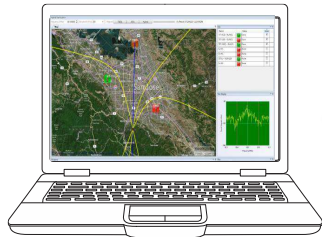
### TCI Solutions Enable:

- License usage validation
- Spectrum Allocation and Optimization
- Interference Mitigation

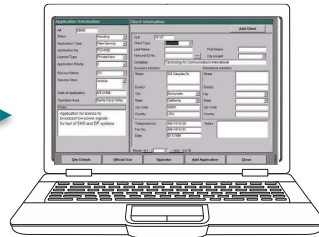


## Spectrum Solution Configuration

Spectrum Processor  
(Scorpio Server)



Scorpio Client



ASMS

## Key Features

- Turn-key Spectrum Solutions with Four Main Elements:
- Scorpio Spectrum Monitoring Client-Server Software
- Spectrum Processor (with Scorpio Server)
- Monitoring and/or Direction Finding Antenna
- Automated Spectrum Management System (ASMS)

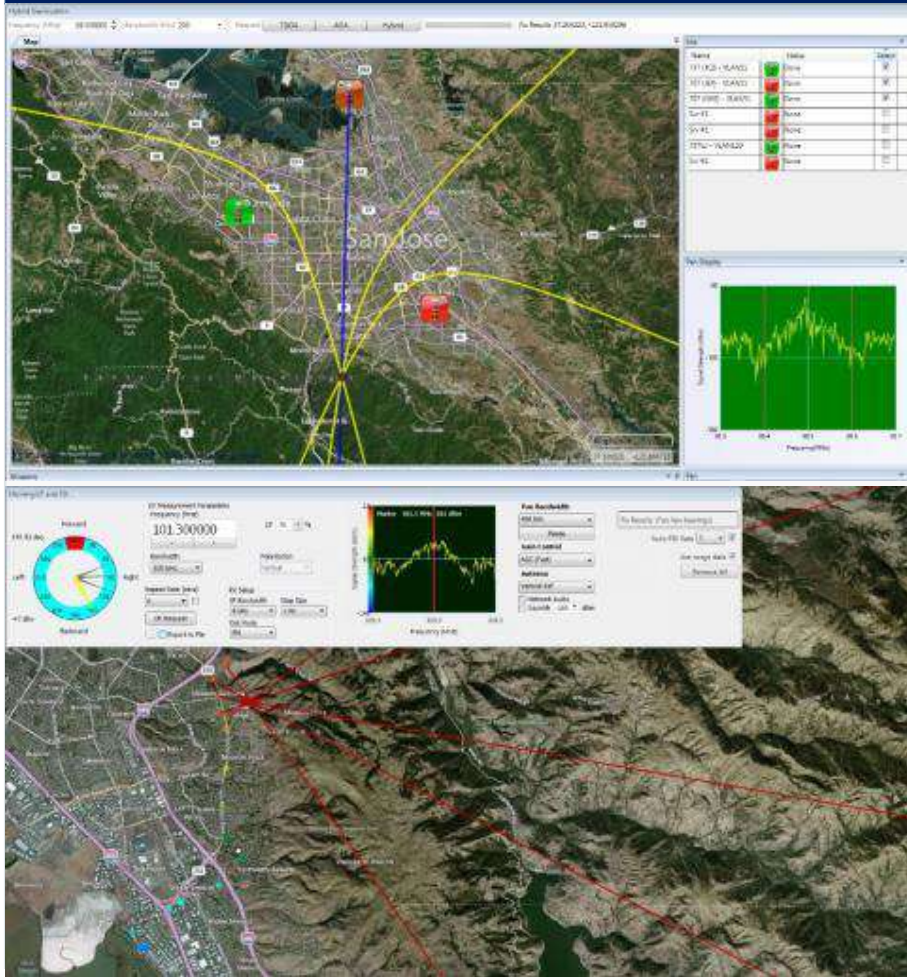
## Complete Monitoring Solutions



## Key Points

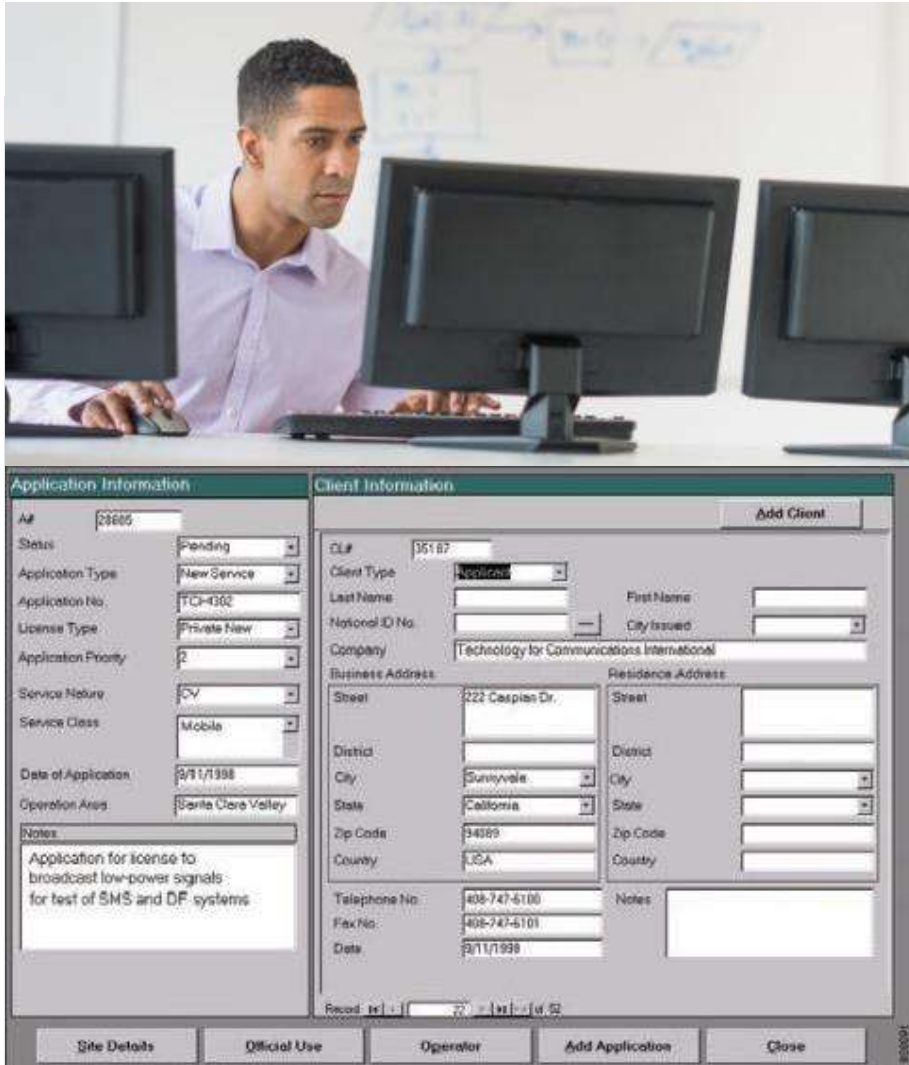
- ITU-Compliant Monitoring
- Angle of Arrival (AOA) Direction Finding
- Time Difference of Arrival (TDOA) Geolocation
- Hybrid AOA / TDOA Geolocation Monitoring Networks
- Fixed, Mobile, Transportable and Man-portable Configurations

## Scorpio's User-Friendly GUI



## Key Points

- Complete command & control of spectrum monitoring & geolocation
- Control multiple servers from one or more clients
- Manual, scheduled & automated monitoring
- Easy to learn and operate
- Built-In-Self-Test (BIST)
- 'Big Data' capabilities



## Key Points

- Provides Automated ITU-Compliant Spectrum Allocation and Regulation
- Administrative, Accounting, Engineering Analysis, and Map Display Functions
- Fully Integrated with TCI Spectrum Monitoring Solutions
- Automated Violation Detection & Reporting

# TCI SMS Solutions In Over 50 Countries



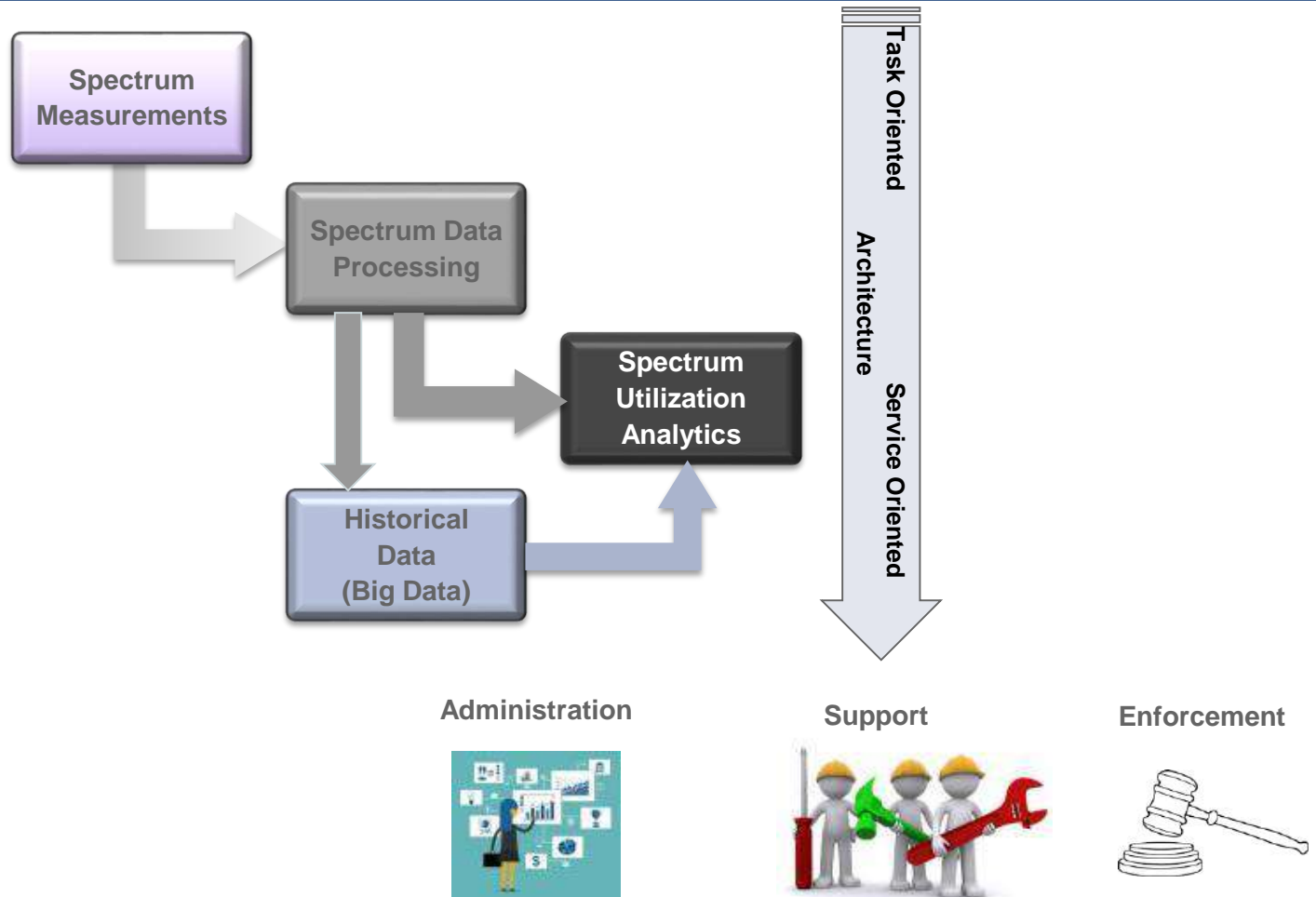
Global reach with over 700 Systems in over 50 countries

# Spectrum Surveyor as Spectrum Management Tool

- Spectrum regulators rely on spectrum utilization data to provide efficient spectrum management
- Spectrum utilization data collected by the spectrum monitoring systems is the basis for spectrum management tasks such as:
  - Maximizing spectrum licensing revenues, spectrum inventory
  - License compliance verification
  - Resolving interference problems
- At the same time, the rapid expansion in wireless communications, both in the number of transmitters and in standards, make achieving optimal monitoring spectrum utilization very challenging.

- Spectrum management encompasses:
  - Spectrum Policy Administration
    - Maximizing spectrum licensing efficiency (revenue)
    - Up to date spectrum inventory (white spaces availability)
    - Real use vs modeled spectrum usage
  - Spectrum Policy Enforcement
    - License compliance verification
    - Elimination of unauthorized illegal use of spectrum
  - Spectrum Policy Support
    - Interference resolution
    - Mis-licensing resolution
    - Coverage confirmation
- Best spectrum management practices greatly benefit from having access to historical measured spectrum information

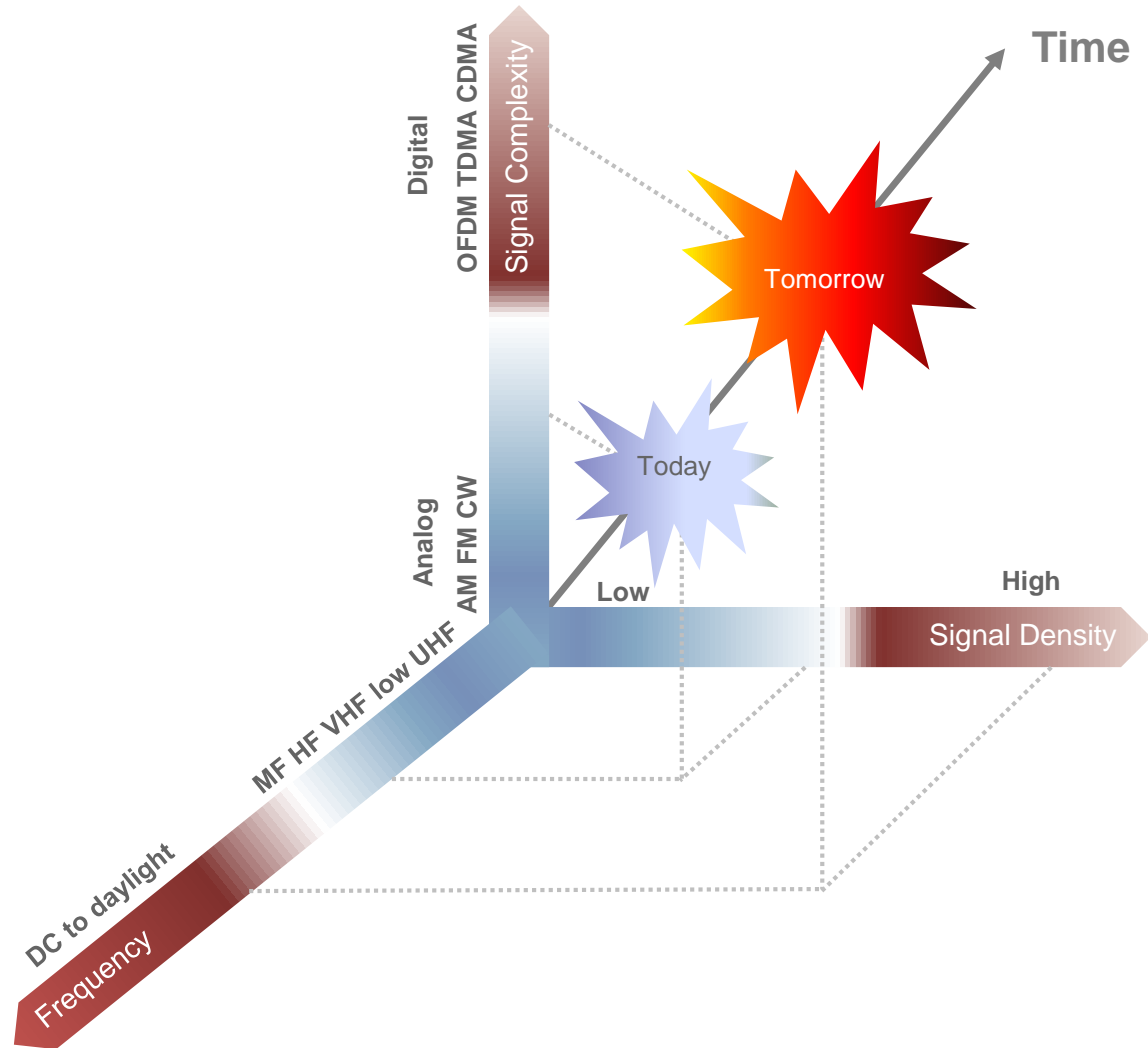
# Spectrum Management - Service Oriented Architecture



- Advances in wireless technology result in:
  - Deployment of communication systems that have shifted to network operation paradigm
  - New frequency bands assignments in order to support high data rates for large number of users
  - Transmission with wider instantaneous bandwidths (tens of MHz) that support high user data rates
  - This results in larger number of lower power emitters deployed in any given area
  - Constant redeployment and expansion of communication networks in order to offer high data rates coverage

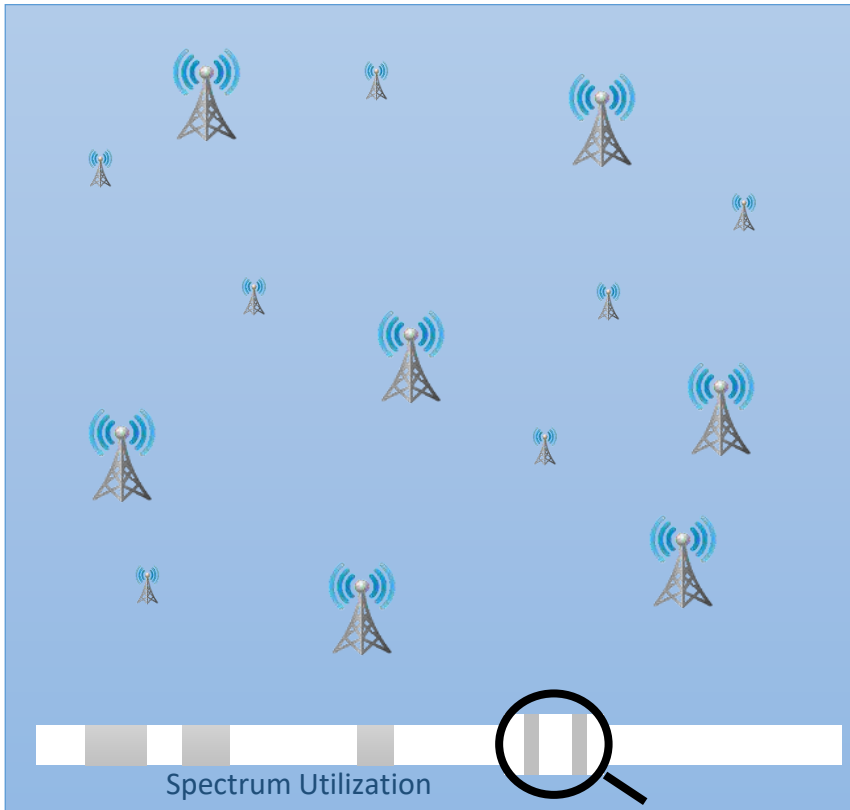
- In order to deal with technology advances modern spectrum monitoring systems (SMS) need to:
  - Monitor network type of emitter deployment (high density at lower power levels), i.e. have monitor network monitor communication networks
  - Monitor 'traditional' emitters such as FM and TV broadcast or air traffic communications
  - Provide more accurate geo-location capability as many similar emitters are now located much closer together
  - Provide high sensitivity to address lower emitter power levels, while working in a difficult RF environment (if there is no communication emitter nearby there will be one soon)

# Communication Trends - World Has Gone Wireless

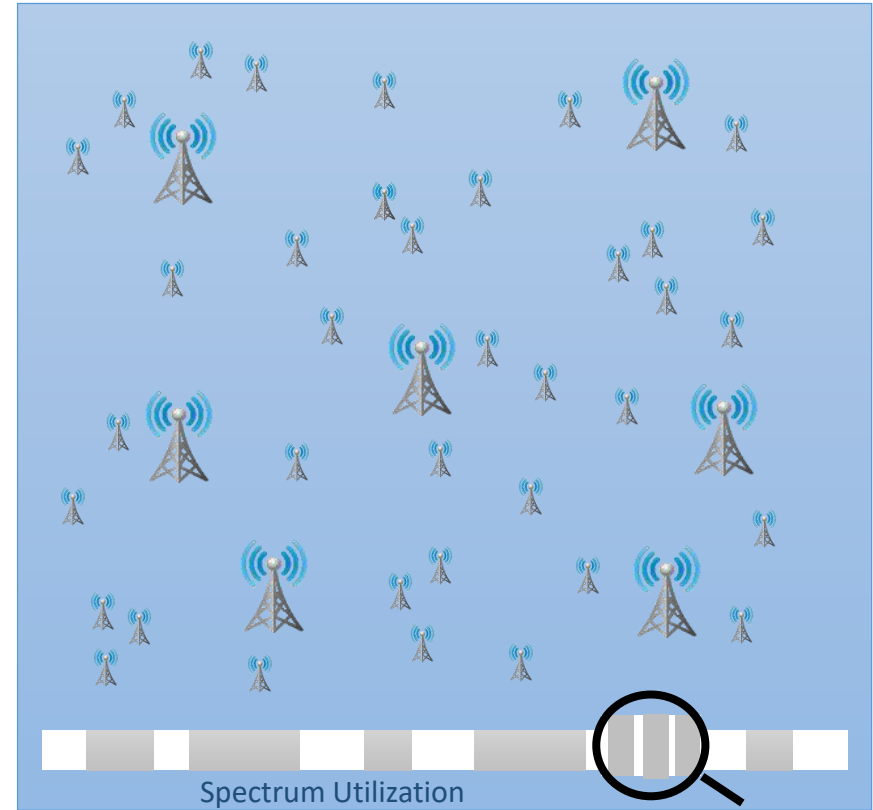


# Trends in Wireless Communications

PAST



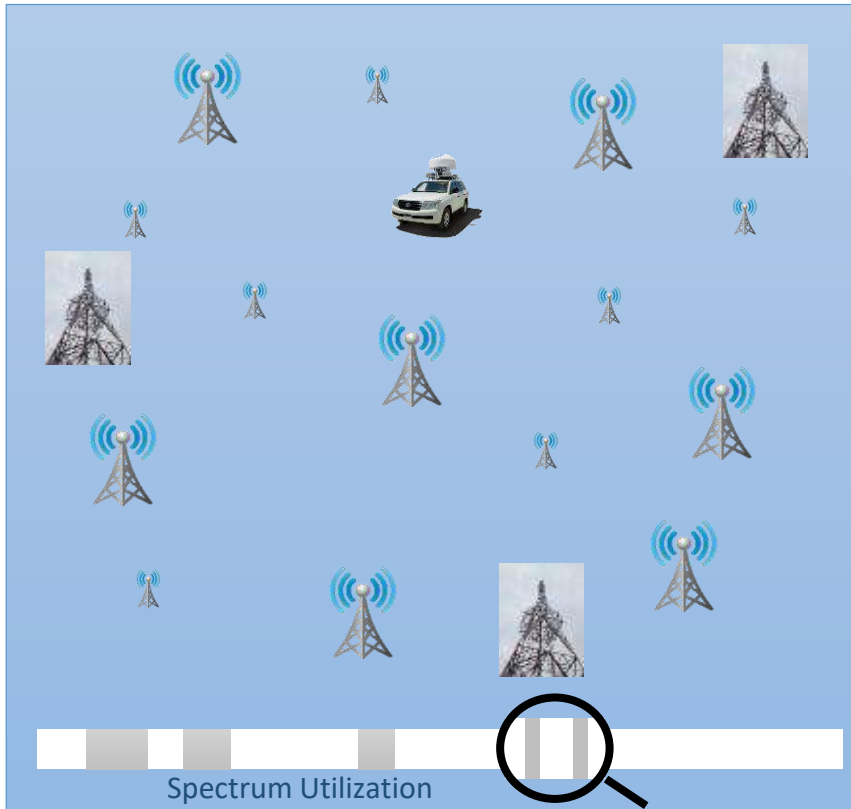
FUTURE



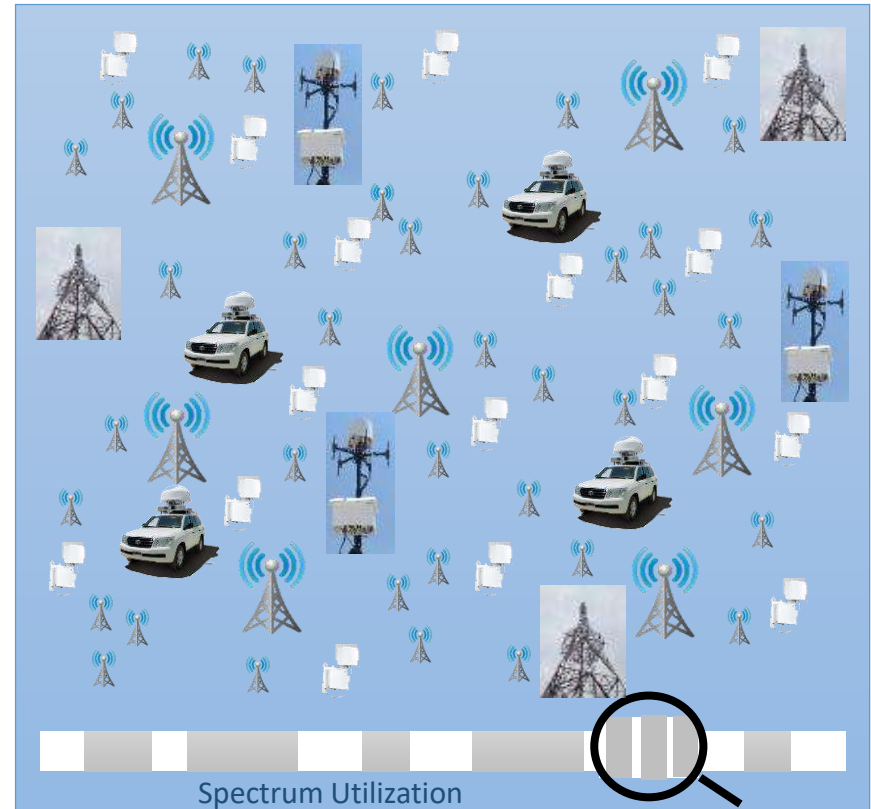
# Spectrum Monitoring System Configuration



PAST



FUTURE



**Traditional  
Fix AOA  
System**



**Mobile  
System**



**Monitoring, AOA & TDOA  
Advanced Fixed, Mobile and  
Transportable System**

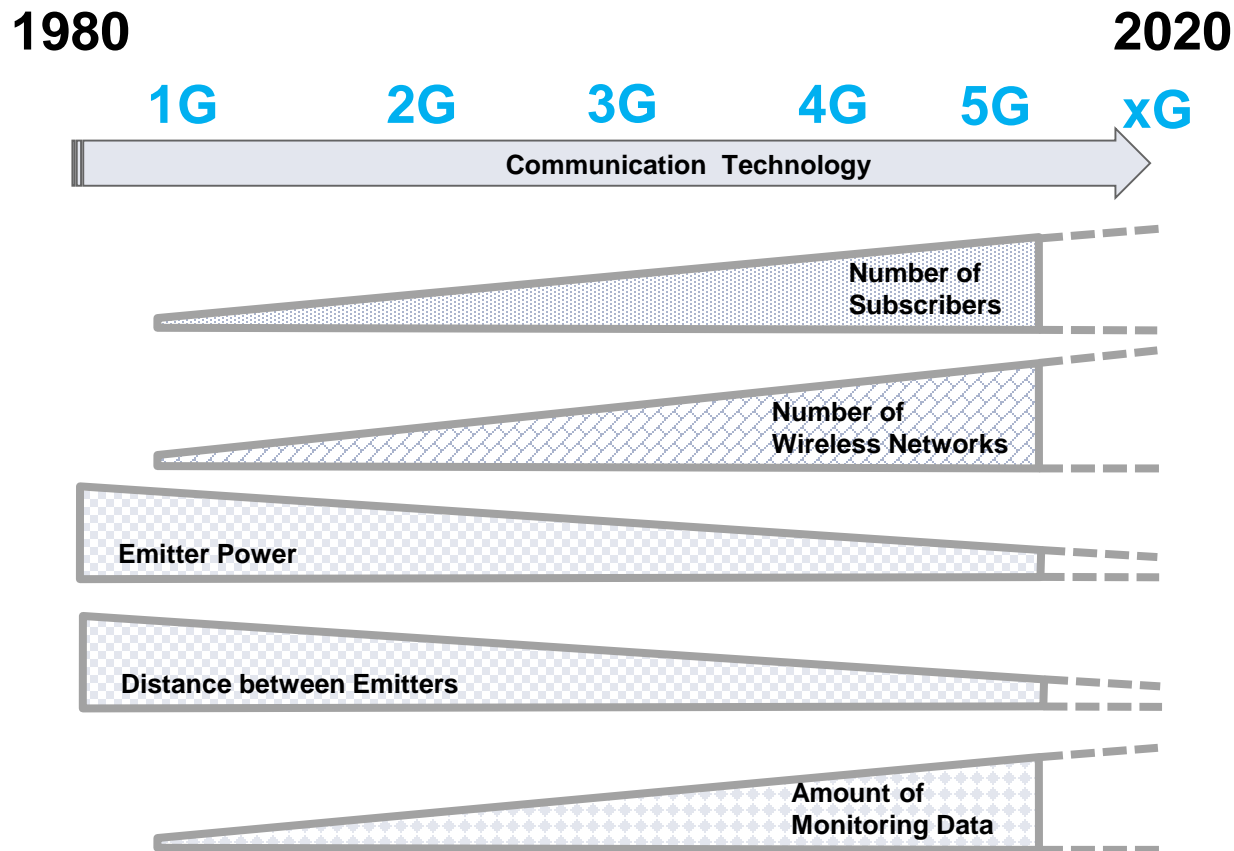


**Monitoring & TDOA  
Advanced Fixed, Mobile  
and Man-portable  
System**



**Advanced Spectrum Monitoring System must deal with  
High Density of Low Power Transmitters**

# Communication technology evolution drives the amount of spectrum information data needed



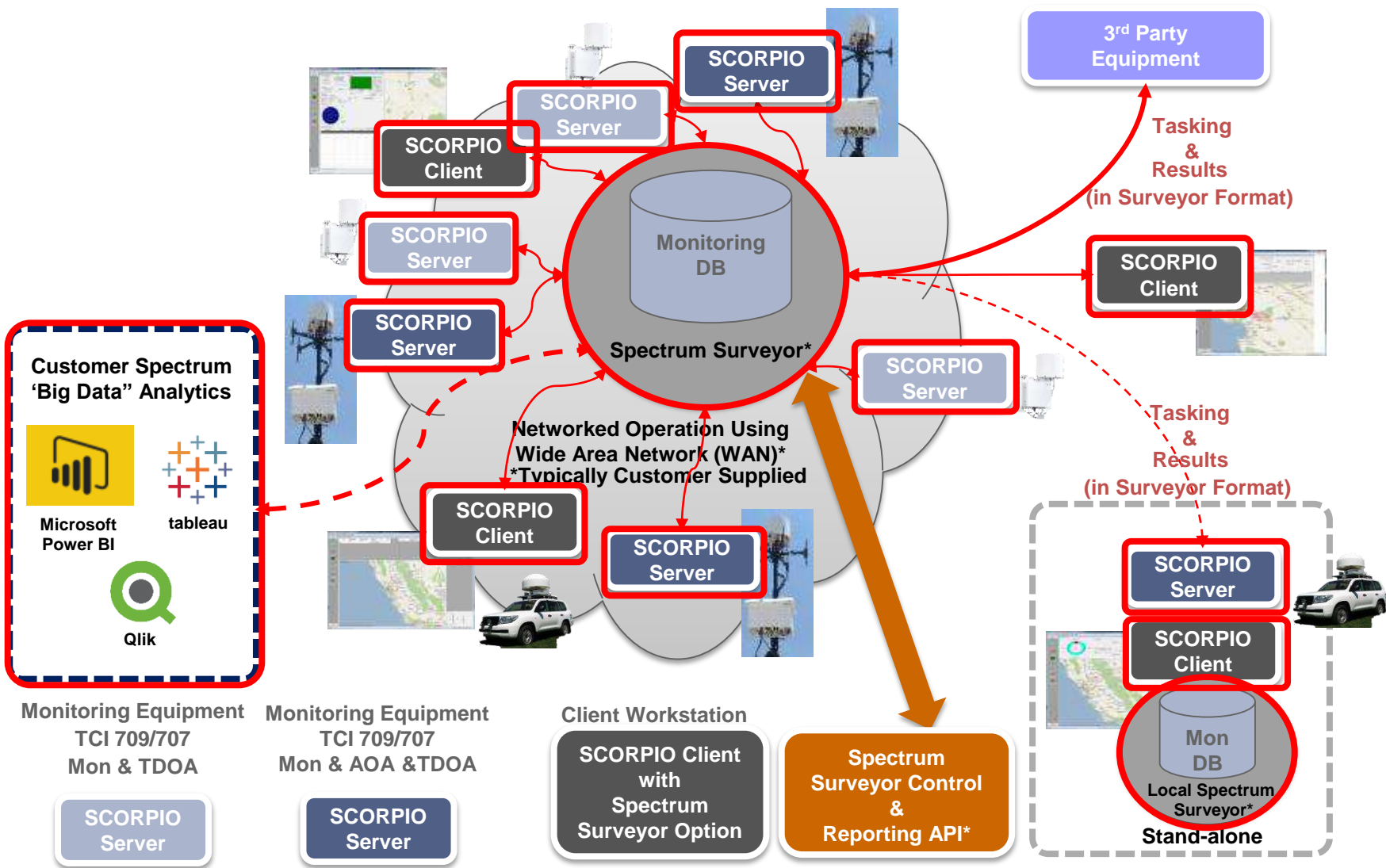


# Spectrum Surveyor – ‘Big Data’ Collection and Data Visualization Analysis option for Scorpio System



- Advanced SMS systems such as TCI’s 709 and 739 support fast and efficient spectrum measurements that result in a large amounts of measurement data (‘big data’)
- In order to further enhance spectrum management in terms of inventorying the spectrum, automatic license verification and interference resolution data from all monitoring servers is integrated in a central database
- Monitoring results can be visualized and analyzed to answer questions related to spectrum management such as:
  - Are there any spectrum white spaces?
  - Are users obeying by license?
  - Was there interference detected?

# Spectrum Surveyor – ‘Big Data’ Collection and Data Visualization Analysis option for Scorpio System



**Customer Spectrum 'Big Data' Analytics**

Microsoft Power BI  
tableau  
Qlik

**Monitoring Equipment TCI 709/707 Mon & TDOA**

**Monitoring Equipment TCI 709/707 Mon & AOA & TDOA**

**Client Workstation SCORPIO Client with Spectrum Surveyor Option**

**Spectrum Surveyor Control & Reporting API\***

**Local Spectrum Surveyor\* Stand-alone**

\*Spectrum Surveyor is an option for Scorpio Monitoring System

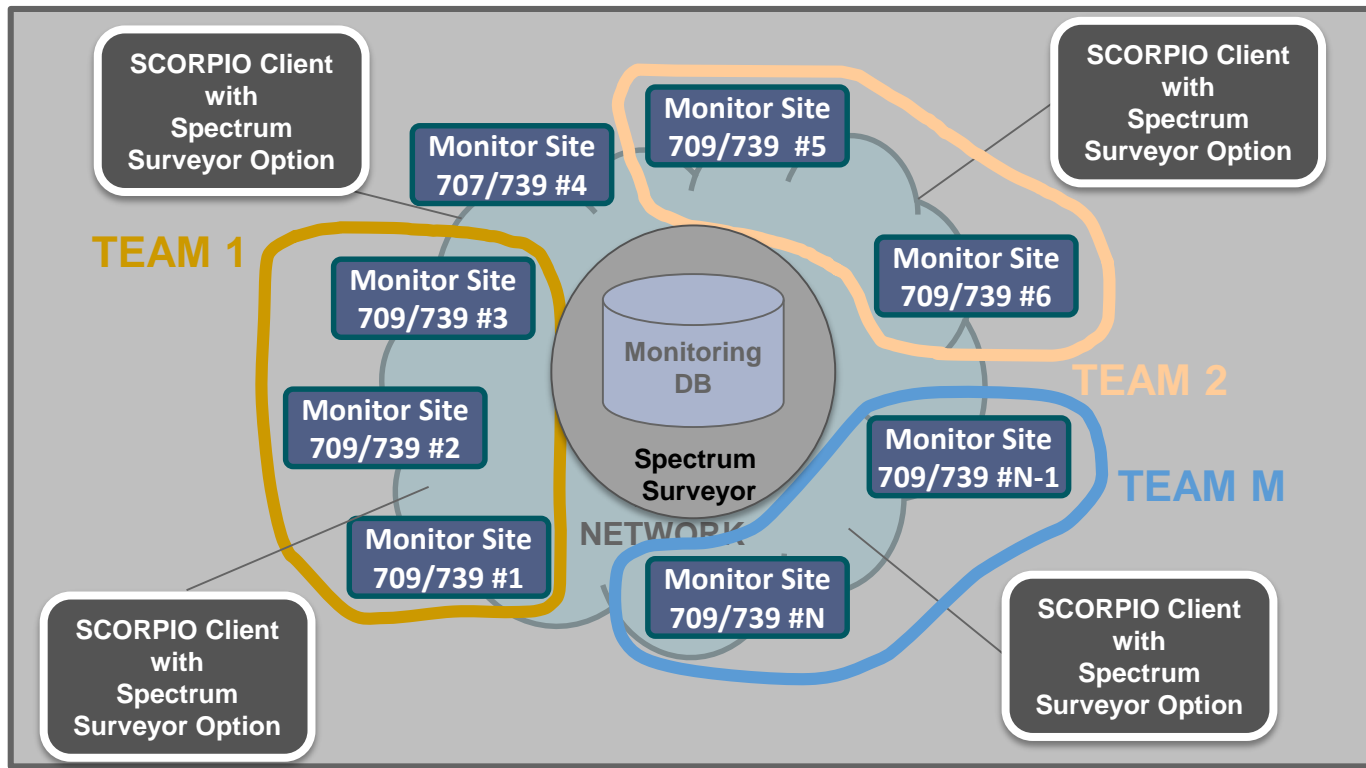
\*\*Customer can deploy spectrum analytics tools to analyze Surveyor data

- Spectrum Surveyor is an option for Scorpio monitoring Systems and it includes several components:
  - SQL database server for storing the monitoring data collected by the Spectrum Surveyor
  - Surveyor management software (typically installed on the same server with SQL database)
  - Spectrum Surveyor operation integrated in SCORPIO client
  - Support for customer provided Business Analytics software for Data Visualization and Business Intelligence
  - Licensable API for tasking Spectrum Surveyor from 3<sup>rd</sup> party applications
  - Open interface for Spectrum Surveyor database

- Spectrum Surveyor operation supports several modes depending on network connectivity availability
  - Networked Mode – this is standard mode in which all the monitoring stations can be tasked from Scorpio client and monitoring results are saved in the central database as soon they are available
  - Stand-alone Mode – in special cases it may be required to collect the monitoring data at the monitoring station that is not networked. In this case a local version of Spectrum Surveyor is required to temporarily save monitoring data until it can be transferred the central database. Data transfer method could use network (if it becomes available) or storage media. Transferred data is merged with the data in central database.

# Spectrum Surveyor Operation – Networked Mode

- N monitor sites are controlled by a Spectrum Surveyor. N sites can be split in non-overlapping teams whereas each team includes some subset of stations. Each station can belong to only one team.



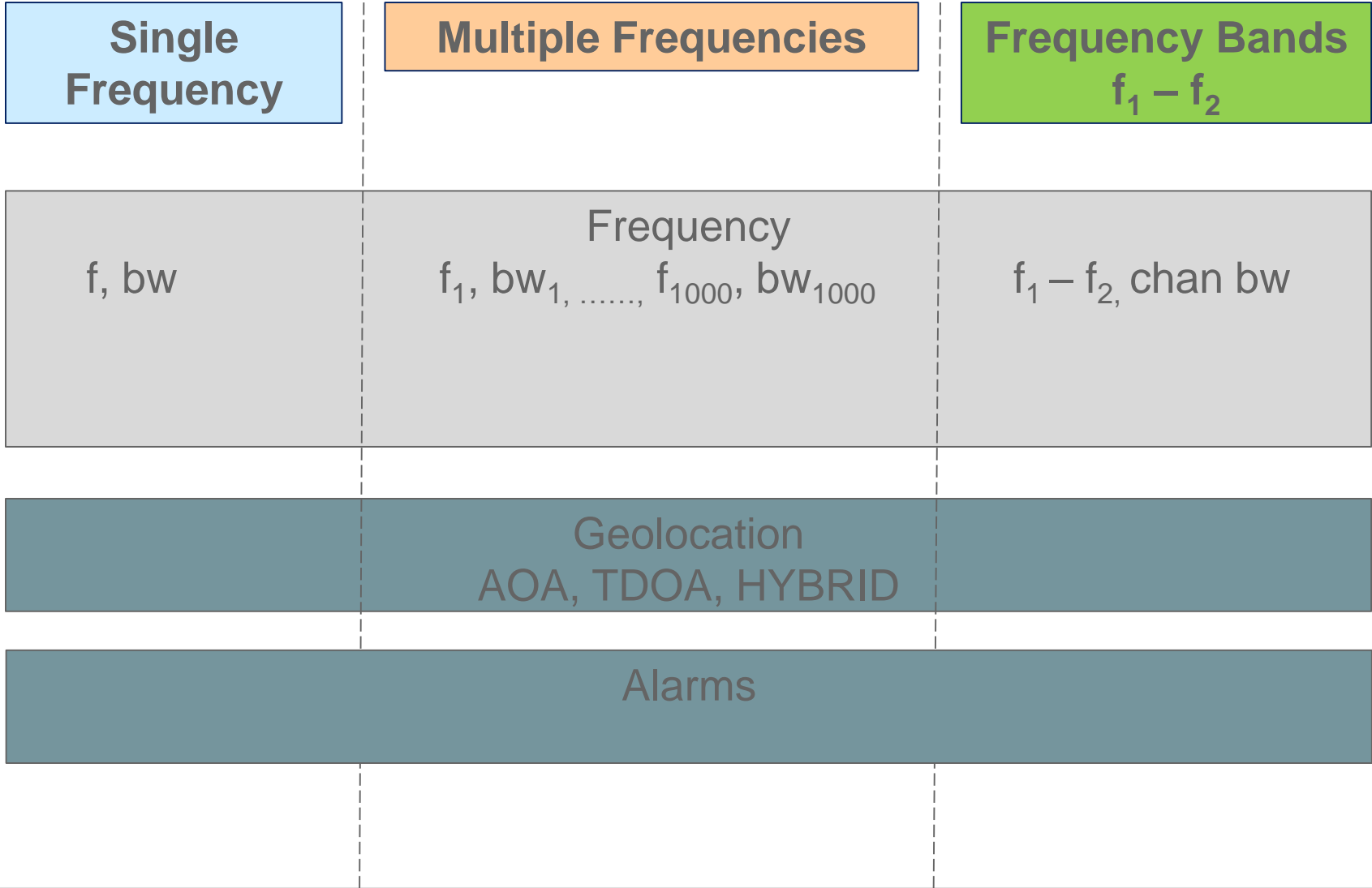
# Example of Spectrum Surveyor Operation with TCI 709 System



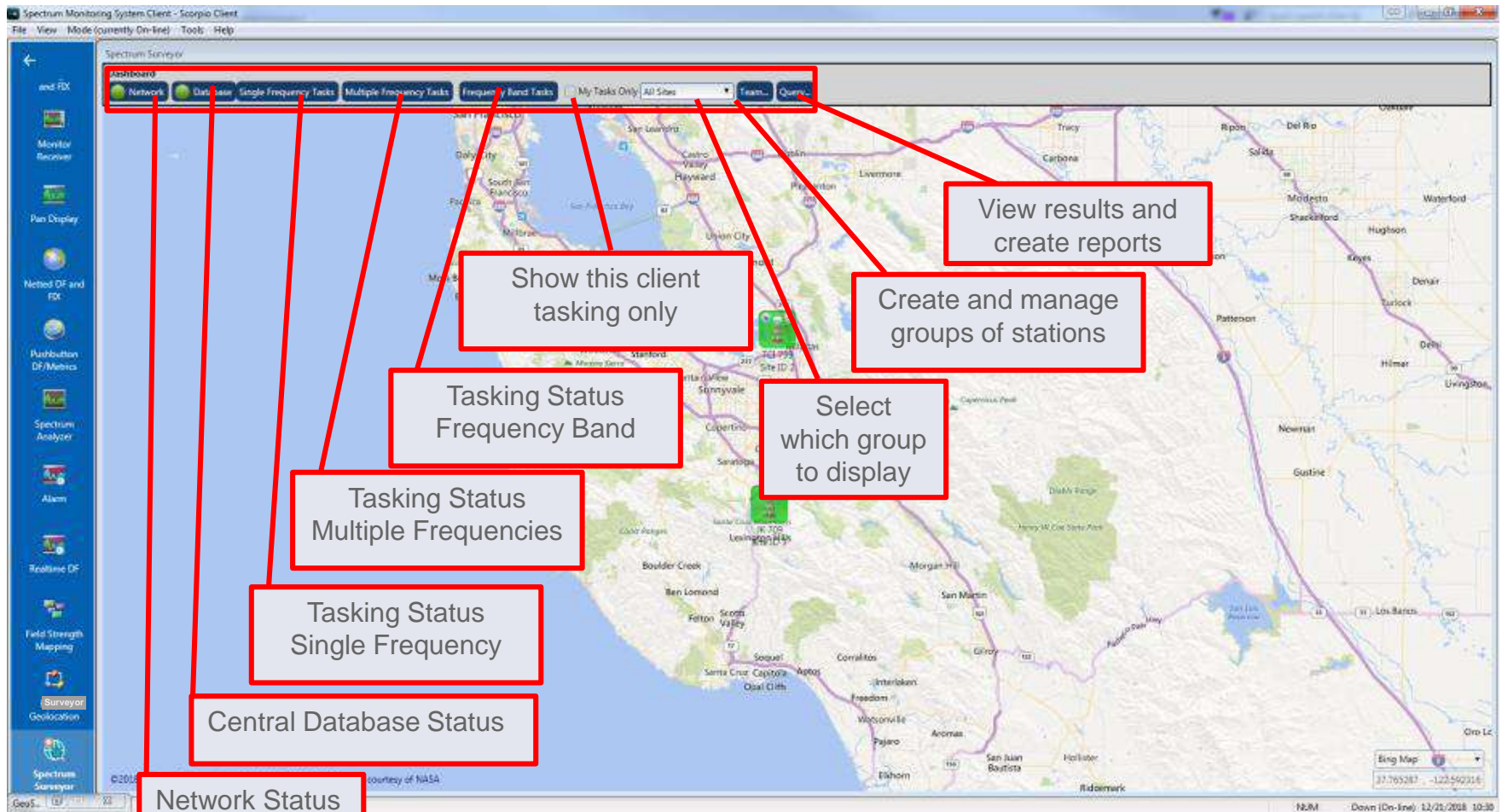
- Using Spectrum Surveyor function operator can task selected group of 709 stations to:
  - Once tasked, continuously monitors single frequency until stopped by user
  - Once tasked, continuously monitors multiple frequencies until stopped by user
  - Once tasked, continuously monitors frequency band  $f_1 - f_2$  until stopped by user

- All task results are automatically saved in central database
- Operator can view task results and create reports by retrieving and analyzing measurement results saved in the central database
- Multiple operators can task same group of stations

# Spectrum Surveyor Operation, cont...



# Spectrum Surveyor Operation uses Dashboard



The screenshot shows the Spectrum Surveyor Dashboard interface. The dashboard includes a navigation menu on the left with icons for various tools like Monitor Receiver, Spectrum Analyzer, and Alarm. The main area displays a map of the San Francisco Bay Area with several callout boxes pointing to specific dashboard elements:

- Network Status**: Points to the 'Network' button in the top navigation bar.
- Central Database Status**: Points to the 'Database' button in the top navigation bar.
- Tasking Status Single Frequency**: Points to the 'Single Frequency Tasks' button in the top navigation bar.
- Tasking Status Multiple Frequencies**: Points to the 'Multiple Frequency Tasks' button in the top navigation bar.
- Tasking Status Frequency Band**: Points to the 'Frequency Band Tasks' button in the top navigation bar.
- Show this client tasking only**: Points to the 'My Tasks Only' dropdown menu in the top navigation bar.
- Select which group to display**: Points to the 'All Sites' dropdown menu in the top navigation bar.
- Create and manage groups of stations**: Points to the 'Tasks...' button in the top navigation bar.
- View results and create reports**: Points to the 'Query...' button in the top navigation bar.

# Spectrum Surveyor – Team Editor



Team Editor

Team Name:

		Site Name	Site ID	Site Type	Sensor Type	Status
<input checked="" type="checkbox"/>		TCI 739	4	Fixed	AOA+TDOA	Available
<input checked="" type="checkbox"/>		JK 709	5	Fixed	Unknown	Available

Save Save As Delete Cancel

# Spectrum Surveyor Single Frequency Tasking function manages creation of Single Frequency tasks



The screenshot displays the 'Single Frequency Tasks' window. It features a 'Task List' table with the following data:

Task ID	Task Name	Frequency (MHz)	Bandwidth (kHz)	Running Status	Tracking
0	Single	101.1	200	Not Running	No
11	Single	101.1	200	Not Running	No

Below the table are 'Task Operations' buttons: 'Start Task...', 'Stop Task', 'Edit Task', 'New Task', and 'Delete Task'. A 'Team List' dropdown menu is set to 'All Sites'. An arrow points from the 'New Task' button to the 'Single Frequency Task' configuration dialog.

The 'Single Frequency Task' dialog includes the following fields:

- Task Name: [ ]
- Frequency (MHz): [ 0 ]
- Bandwidth (kHz): [ 0 ]
- Threshold:  SNR [ 0 ] dB,  Level [ 0 ] dBuV/m
- Geolocation:  TDOA
- Buttons: Save, Cancel

# Spectrum Surveyor Multiple Frequencies Tasking function manages creation of multiple frequencies task



Multiple Frequency Task

Task Name

Frequency / Bandwidth List

Frequency (MHz)	Bandwidth (kHz)	okEd

Threshold

SNR  dB

Level  dBuV/m

Multiple Frequency Tasks

Task List

Task ID	Task Name	Min Frequency (MHz)	Max Frequency (MHz)	# of Frequencies	Status
12	List	88.5	105.7	3	Not Running

Task Details

Frequency (MHz)	Bandwidth (kHz)
88.5	200
101.3	200
105.7	200

Task Operations

Team List:

# Spectrum Surveyor Frequency Band Tasking function manages creation of Frequency Band tasks



**Frequency Band Task**

Task Name

Start Frequency (MHz)  End Frequency (MHz)

Bandwidth Resolution (kHz)

Threshold

SNR  dB

Level  dBuV/m

**Frequency Band Tasks**

Task List

Task ID	Task Name	Start Frequency (MHz)	End Frequency (MHz)	Bandwidth Resolution (kHz)	Running Status
5	AeroNauticalBand	118	138	25	Running
6	CellBand	850	950	200	Running
7	FM Band	88.1	107.9	200	Running

Task Operations

Team List



# Spectrum Surveyor Query function supports viewing of measurements results and report creation



**Survey Data Query**

**Date/Time**

Start Date/Time  
Wednesday, December 19, 2018 3:58:37 PM

End Date/Time  
Saturday, December 22, 2018 4:10:58 PM

**Time of Day**

Any Time in the Day  
 Range of Time in the Day  
Start: 04:03:37 PM  
End: 04:03:37 PM

**Repeat**

**Query Mode**

Query By Task  
 Query Manually

AOA  
 TDOA  
 Geo FIX  
 Spectrum Occupancy

**Task List**  
AreoNauticalBand

Limit Results by Team  
Team List  
All Sites

Limit Results by Site  
Site List

**Frequency**

Any Frequency  
 Frequency Range  
Start Frequency: 118 (MHz)  
End Frequency: 138 (MHz)

Occupancy  
 Field Strength

# Built-in Data Visualization – Query Results



Survey Data Query Results

Filter Results

Sensors

Site Name	Site Type	Sensor Type
JK 709	Fixed	TDOA
TCI 739	Fixed	AOA+TDOA

Select All Deselect All

Frequencies

Frequency (MHz)
92.3
92.5
92.7
92.9
93.1
93.3
93.5
93.7

Select All Deselect All

Date/Time Range

Start Time: Thursday, December 20, 2018 10:35:18  
 End Time: Saturday, December 22, 2018 10:40:18

Hide 0 Occupancy Entries  
 Hide null Field Strength Entries

Refine Query Clear Filtering

Spectrum Occupancy Data Data on Map

Frequency (MHz)	Average Occupancy	Max Occupancy	Average Field Strength	Max Field Strength	Result Date/Time	Site Name	Site ID
92.3	100	100	58	60	12/20/2018 3:40:00 PM	JK 709	3
93.3	100	100	51	52	12/20/2018 3:40:00 PM	JK 709	3
94.1	100	100	66	67	12/20/2018 3:40:00 PM	JK 709	3
94.5	100	100	57	58	12/20/2018 3:40:00 PM	JK 709	3
94.9	100	100	51	52	12/20/2018 3:40:00 PM	JK 709	3
95.1	51	51	49	54	12/20/2018 3:40:00 PM	JK 709	3
95.3	100	100	84	84	12/20/2018 3:40:00 PM	JK 709	3
95.5	50	50	49	54	12/20/2018 3:40:00 PM	JK 709	3
95.7	100	100	51	52	12/20/2018 3:40:00 PM	JK 709	3
96.1	100	100	53	55	12/20/2018 3:40:00 PM	JK 709	3
96.5	100	100	51	53	12/20/2018 3:40:00 PM	JK 709	3
97.3	100	100	59	60	12/20/2018 3:40:00 PM	JK 709	3
97.5	100	100	47	48	12/20/2018 3:40:00 PM	JK 709	3
97.7	100	100	66	68	12/20/2018 3:40:00 PM	JK 709	3
97.9	100	100	49	50	12/20/2018 3:40:00 PM	JK 709	3
98.1	100	100	59	61	12/20/2018 3:40:00 PM	JK 709	3
98.3	100	100	79	80	12/20/2018 3:40:00 PM	JK 709	3
98.5	100	100	103	103	12/20/2018 3:40:00 PM	JK 709	3
98.7	100	100	81	81	12/20/2018 3:40:00 PM	JK 709	3
98.9	100	100	56	58	12/20/2018 3:40:00 PM	JK 709	3
99.1	100	100	47	48	12/20/2018 3:40:00 PM	JK 709	3
99.7	100	100	59	60	12/20/2018 3:40:00 PM	JK 709	3
100.3	100	100	53	54	12/20/2018 3:40:00 PM	JK 709	3
101.3	100	100	62	63	12/20/2018 3:40:00 PM	JK 709	3
102.1	100	100	59	61	12/20/2018 3:40:00 PM	JK 709	3
102.9	100	100	51	52	12/20/2018 3:40:00 PM	JK 709	3
103.7	100	100	57	58	12/20/2018 3:40:00 PM	JK 709	3
104.5	100	100	57	58	12/20/2018 3:40:00 PM	JK 709	3
104.9	100	100	60	61	12/20/2018 3:40:00 PM	JK 709	3
105.1	100	100	47	48	12/20/2018 3:40:00 PM	JK 709	3
105.3	100	100	52	53	12/20/2018 3:40:00 PM	JK 709	3
105.7	100	100	75	76	12/20/2018 3:40:00 PM	JK 709	3

# Built-in Data Visualization – Query Results

Survey Data Query Results
← □ □ ×

**Filter Results**

**Sensors**

<input type="checkbox"/>	Site Name	Site Type	Sensor Type
<input checked="" type="checkbox"/>	JK 709	Fixed	TDOA
<input checked="" type="checkbox"/>	TCI 739	Fixed	AOA+TDOA

**Frequencies**

<input type="checkbox"/>	Frequency (MHz)
<input checked="" type="checkbox"/>	92.3
<input checked="" type="checkbox"/>	92.5
<input checked="" type="checkbox"/>	92.7
<input checked="" type="checkbox"/>	92.9
<input checked="" type="checkbox"/>	93.1
<input checked="" type="checkbox"/>	93.3
<input checked="" type="checkbox"/>	93.5
<input checked="" type="checkbox"/>	93.7
<input checked="" type="checkbox"/>	93.9

**Date/Time Range**

Start Time  End Time

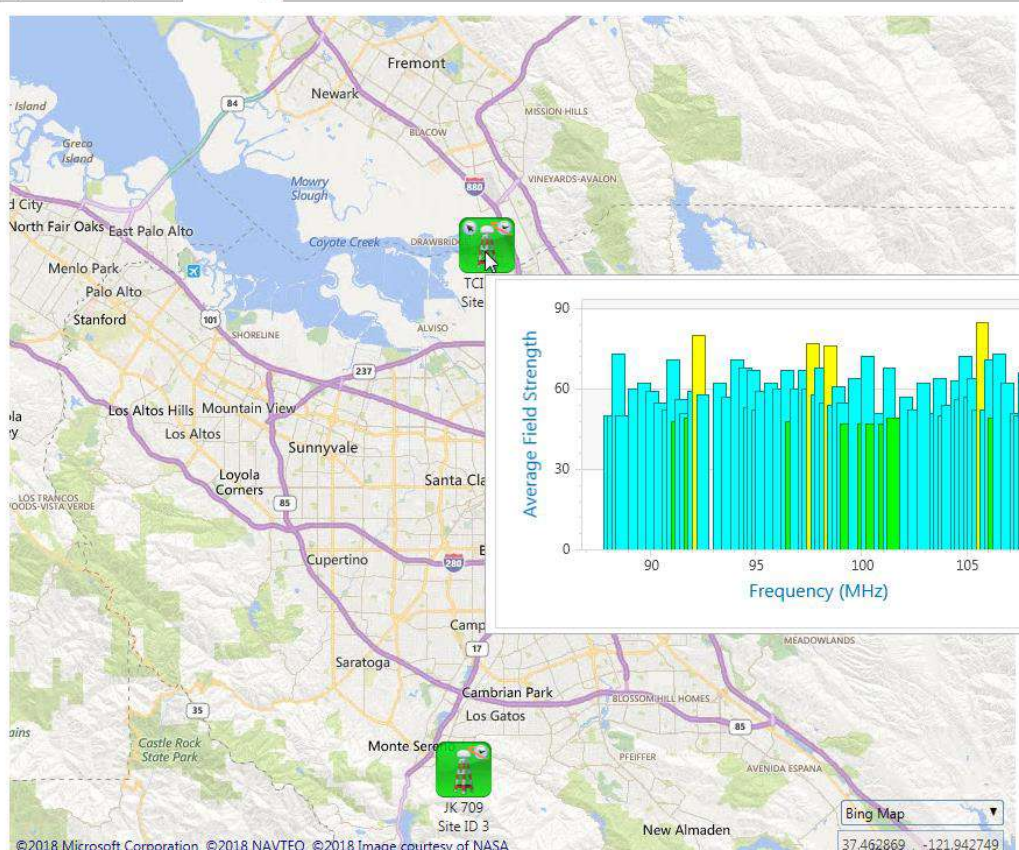
Start Time

End Time

Hide 0 Occupancy Entries

Hide null Field Strength Entries

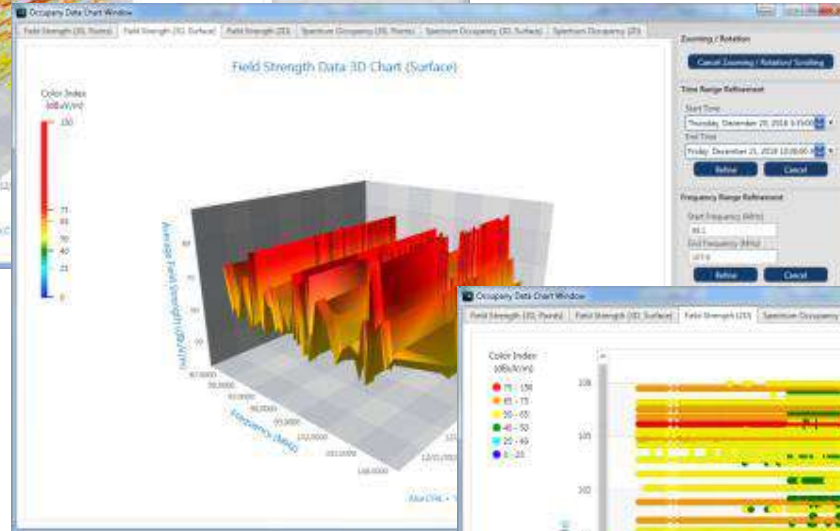
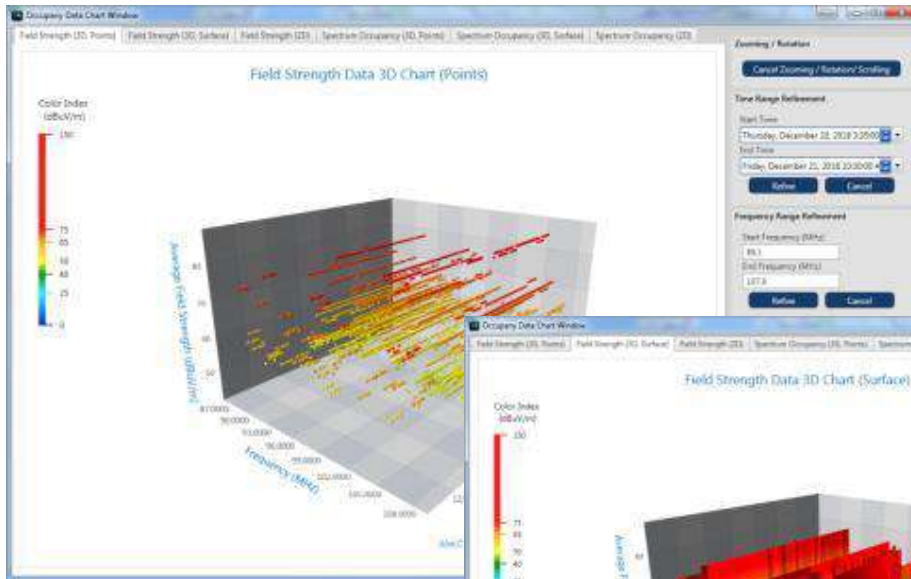
Spectrum Occupancy Data    Data on Map



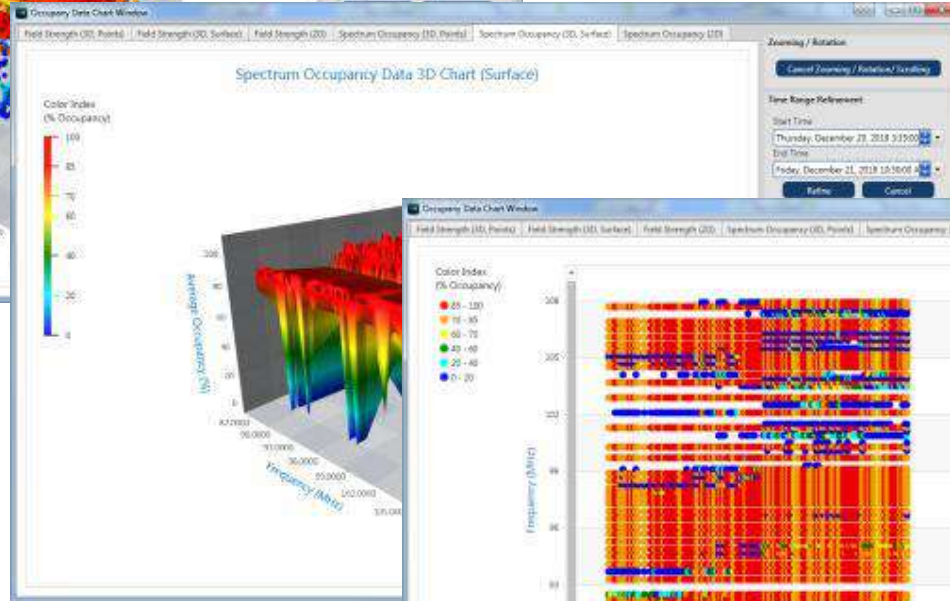
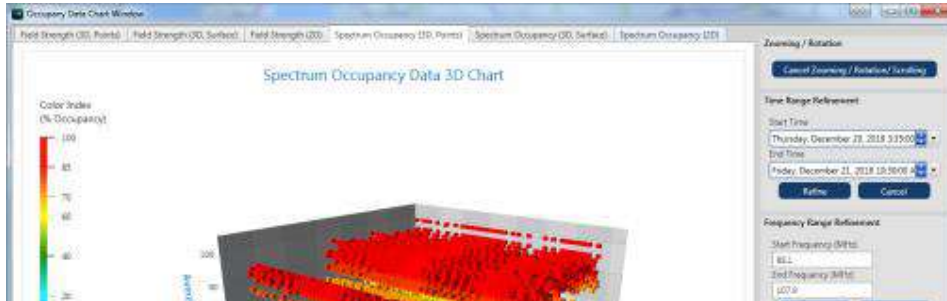
37.462869, -121.942749

©2018 Microsoft Corporation, ©2018 NAVTEQ, ©2018 Image courtesy of NASA

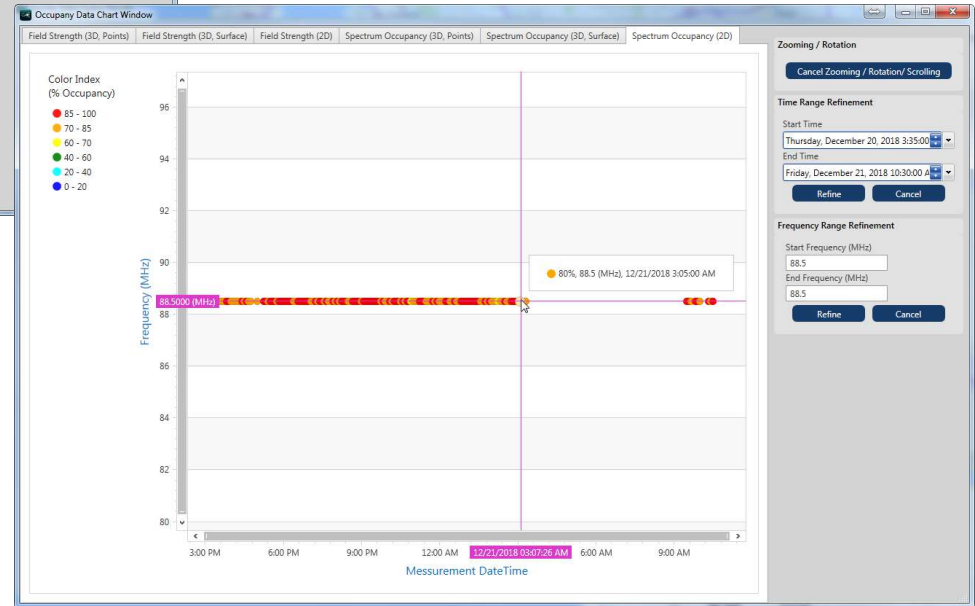
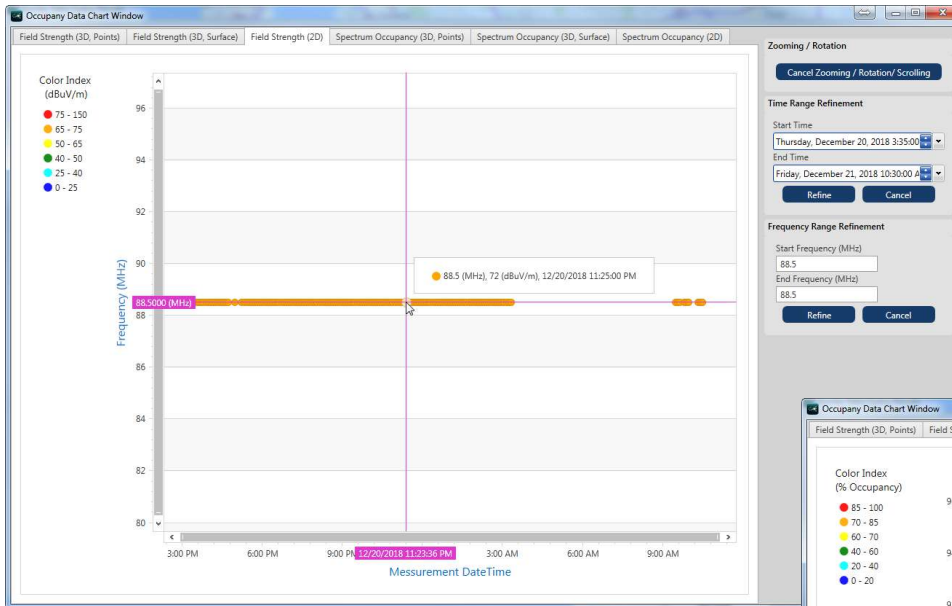
# Built-in Data Visualization – Query Results



# Built-in Data Visualization – Query Results

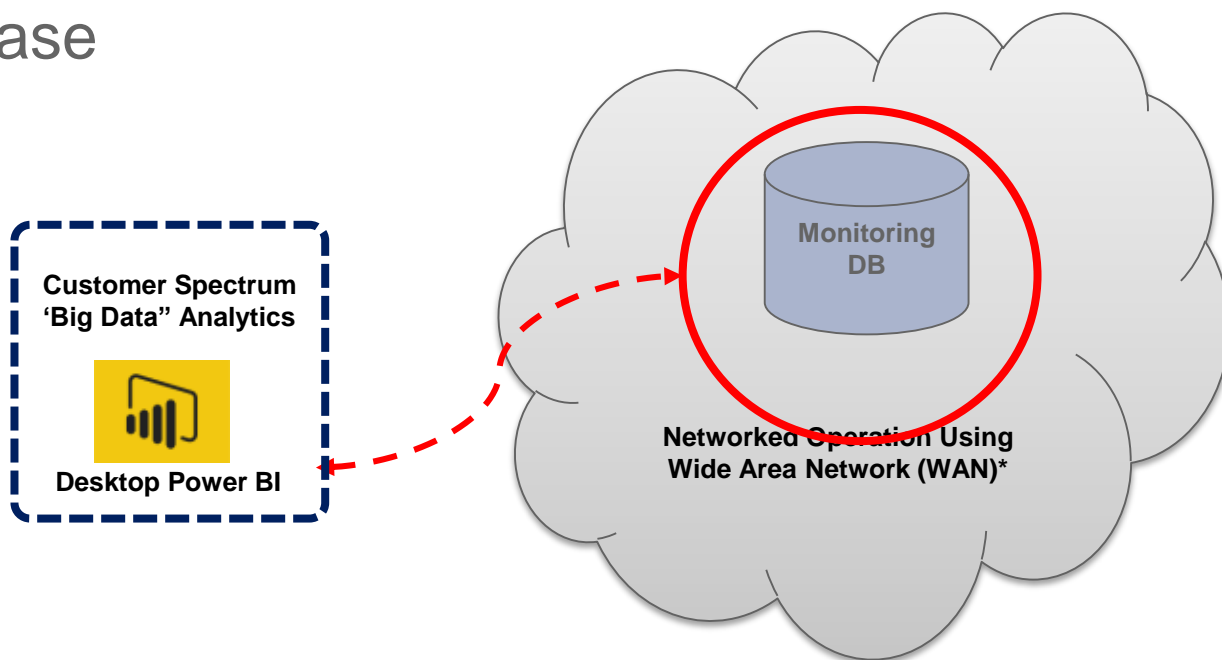


# Built-in Data Visualization – Query Results

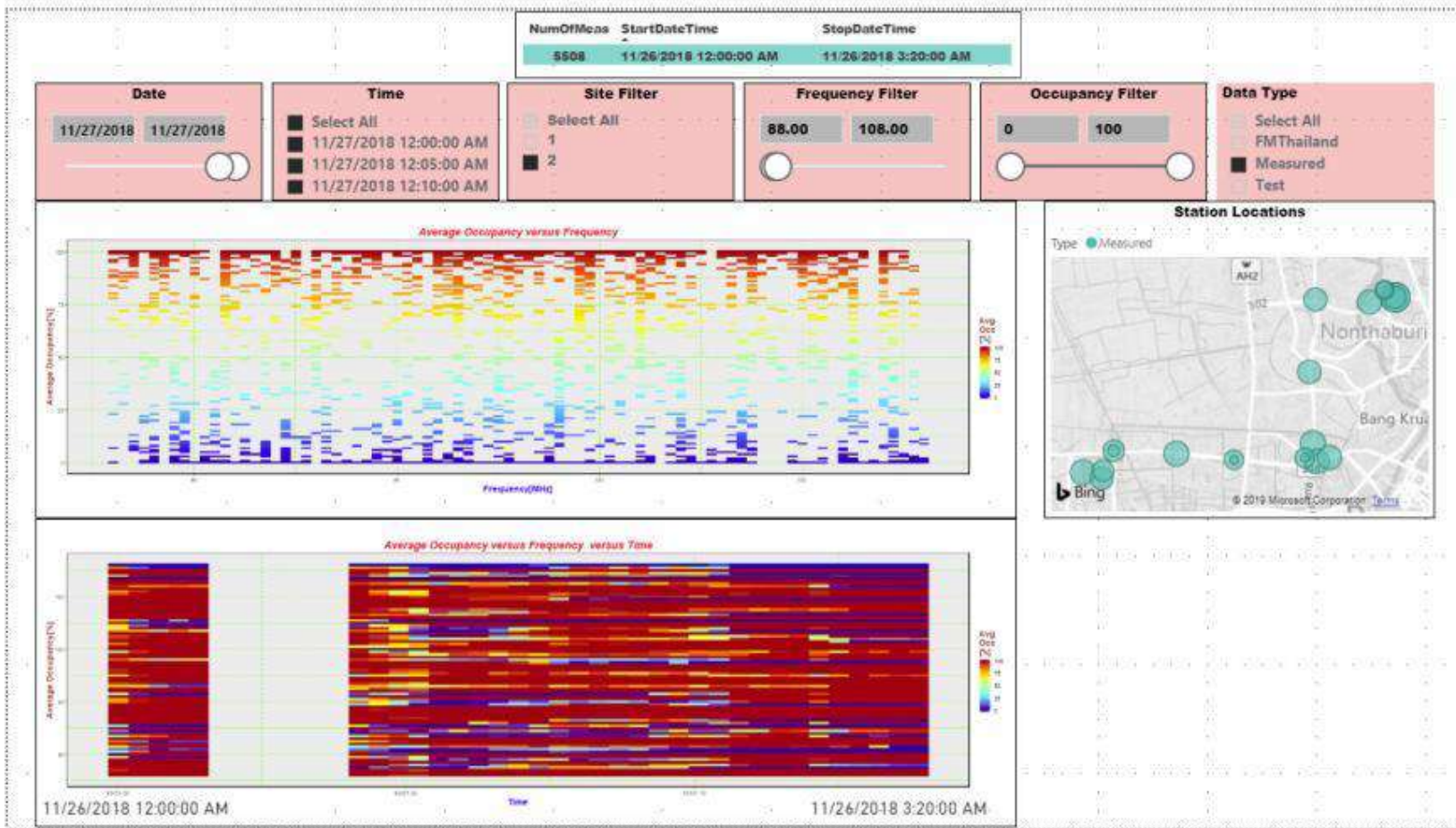


- Spectrum data collected by Surveyor is available for analysis using external visualization and analysis tools
- There are number of visualization and data analysis tools that are used for business data mining. These tools include:
  - Power BI from Microsoft
  - Tableau
  - Qlik
  - Others
- Custom data visualization tools are typically selected by spectrum management organization as these tools might be used for other types of analysis beside spectrum data

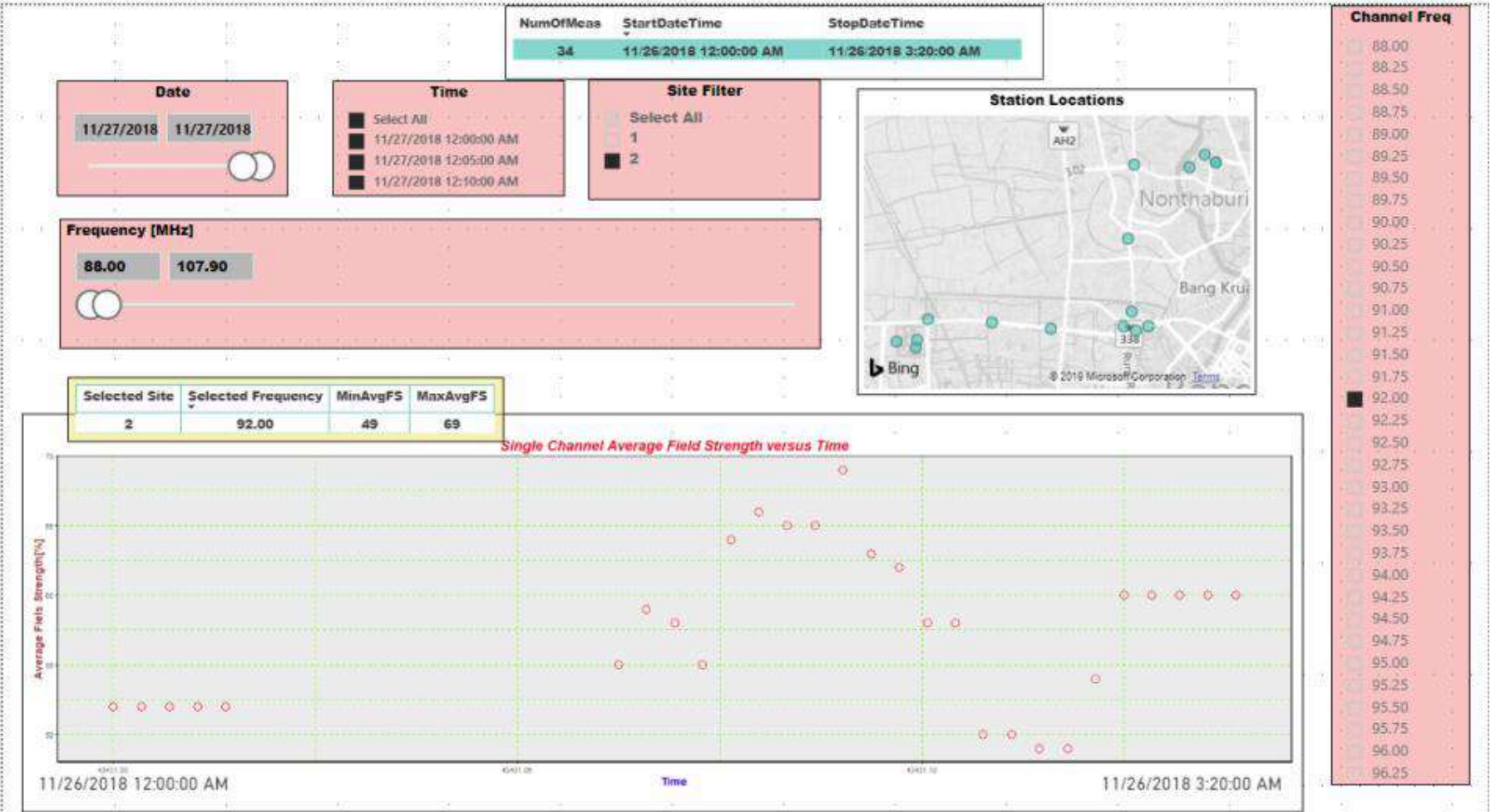
- TCI has developed example Power BI dashboards for the analysis of spectrum data
- In these examples the desktop version of Power BI is used to analyze the data stored in Surveyor SQL data base



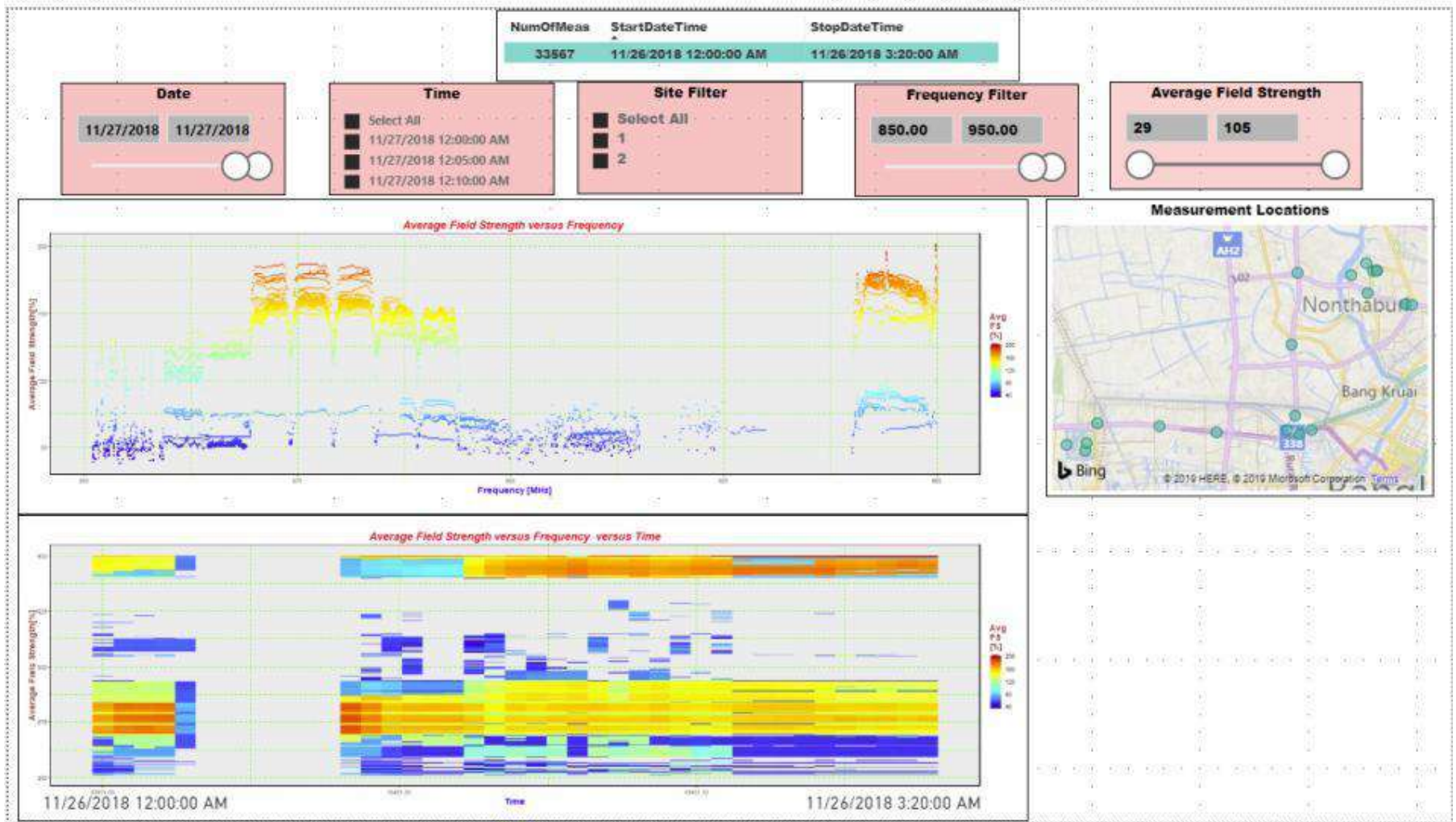
# Custom Power BI Visualization



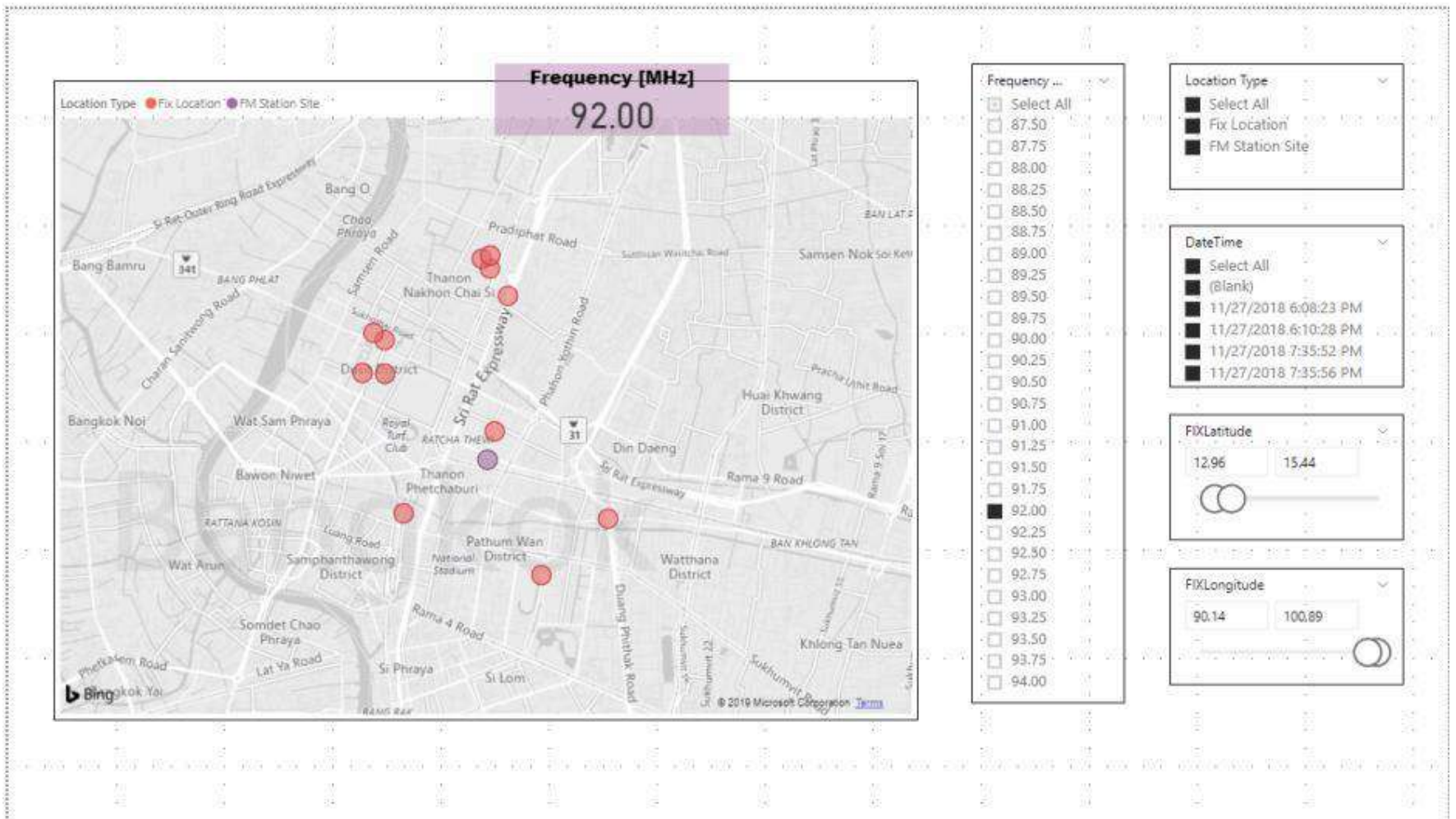
# Custom Power BI Visualization



# Custom Power BI Visualization



# Custom Power BI Visualization



# Custom Power BI Visualization



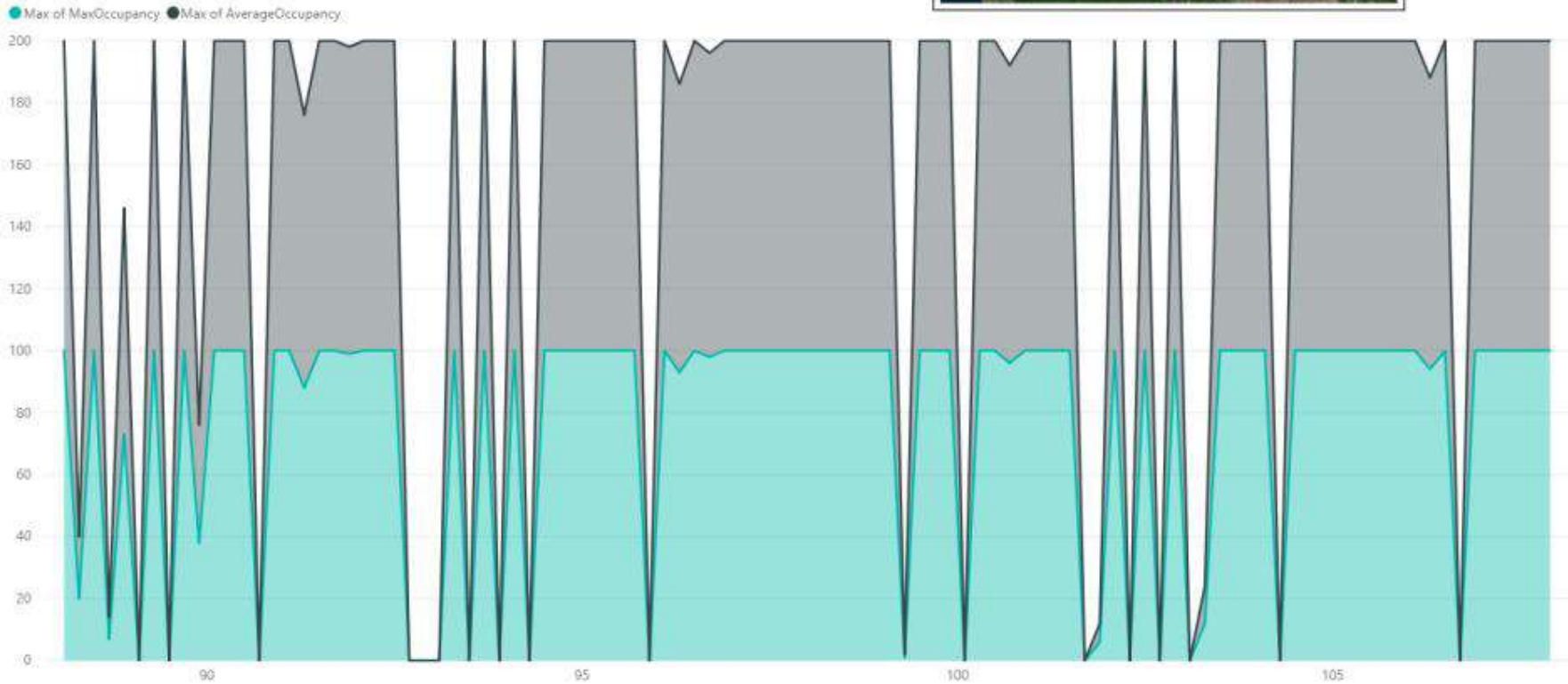
**Date**  
5/9/2019 5/13/2019

**Time**  
 Select All  
 5/9/2019 6:20:00 PM  
 5/9/2019 6:25:00 PM  
 5/9/2019 6:30:00 PM

**Frequency [MHz]**  
88.10 107.90

**Site Filter**  
 Select All  
 2  
 3  
 4

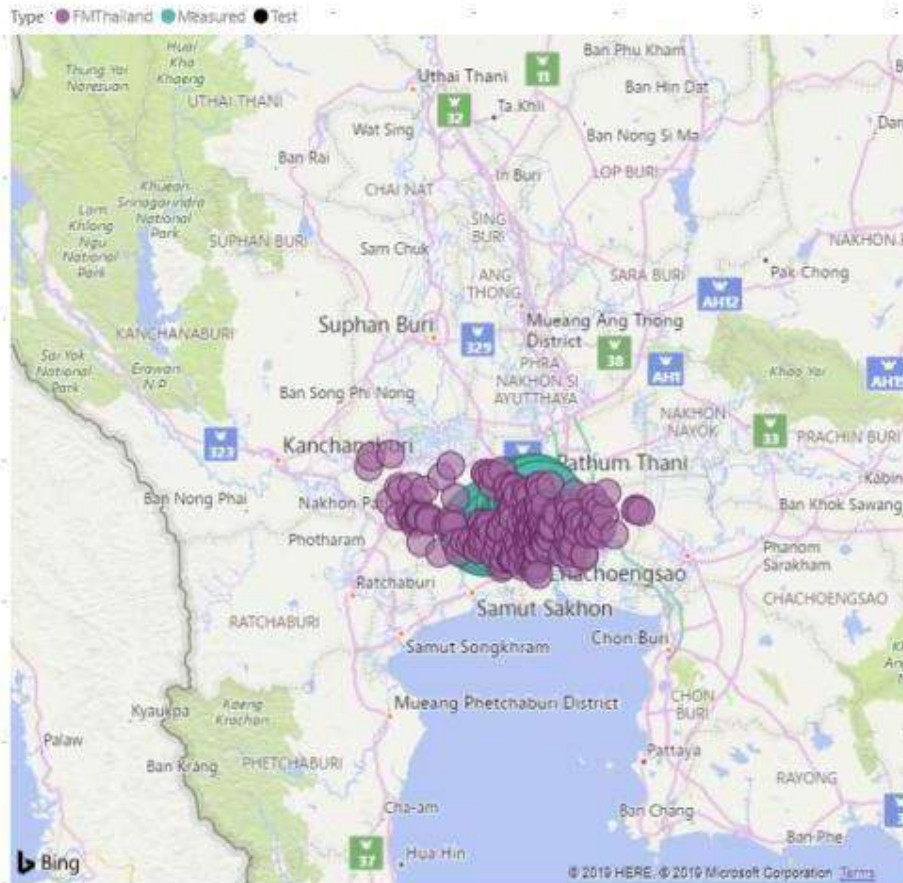
**Station Locations**  
Map showing station locations: Redwood City, Palo Alto, Sunnyvale, Milpitas, Coyote Creek, San Jose. Includes Bing logo and copyright information.



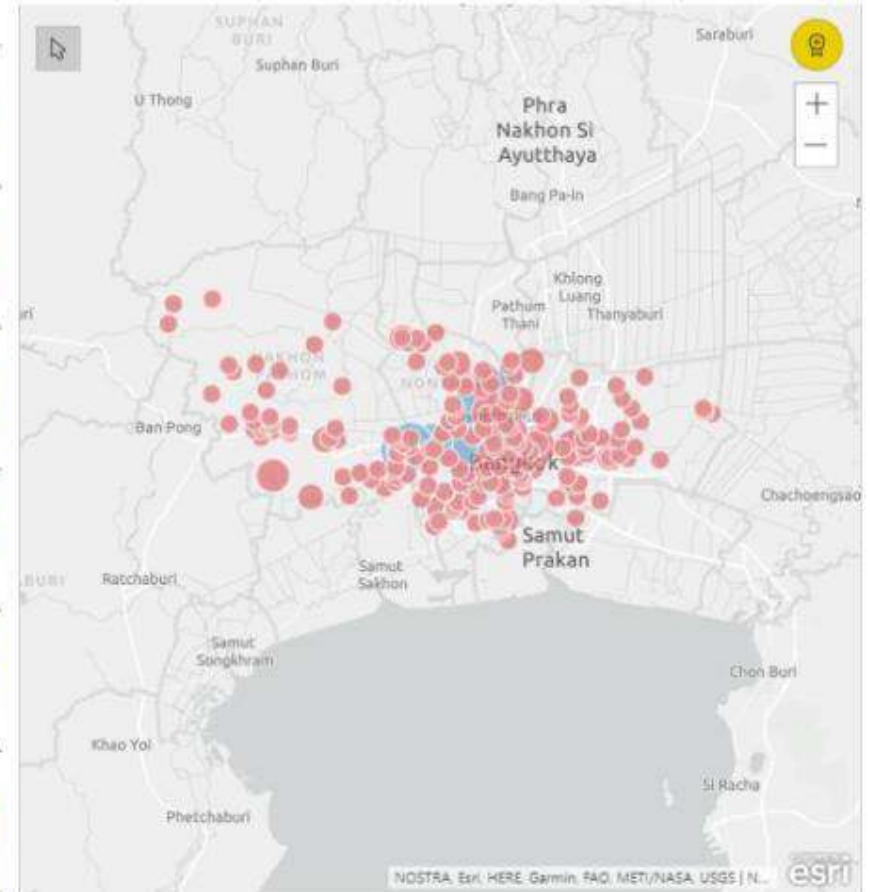
# Custom Power BI Visualization



BING Maps



ArcGIS Maps



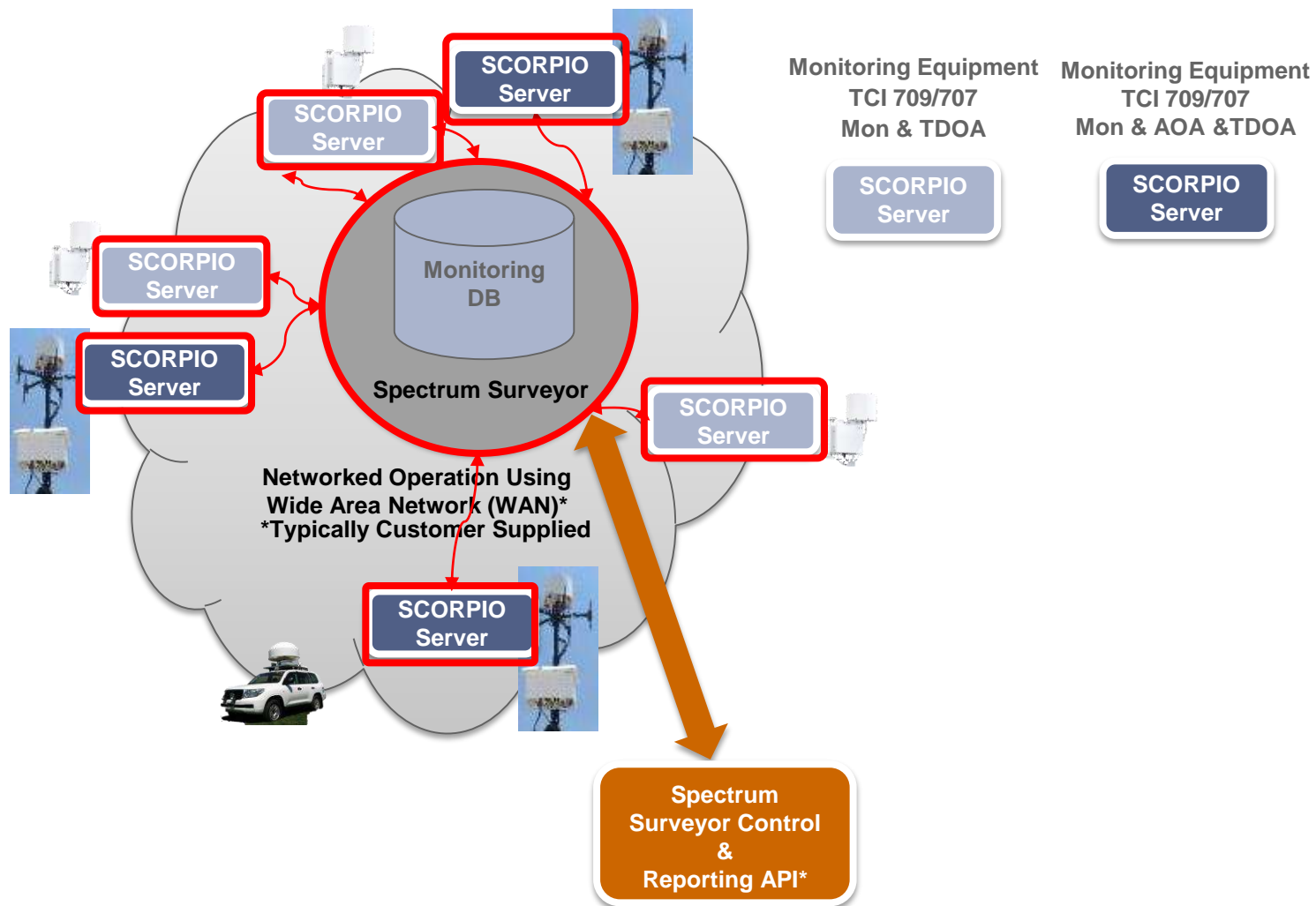
# Custom Visualization and Analysis Deployment using Power BI



- Desktop Power BI
  - Free application – individual workstation produce their own visualization and analysis
- Power BI Report Server plus Desktop Power BI for Report Server
  - Report Server is on organization premises
  - Reports are sharable inside the firewall
- Power BI Service
  - Full cloud based data visualization and analysis

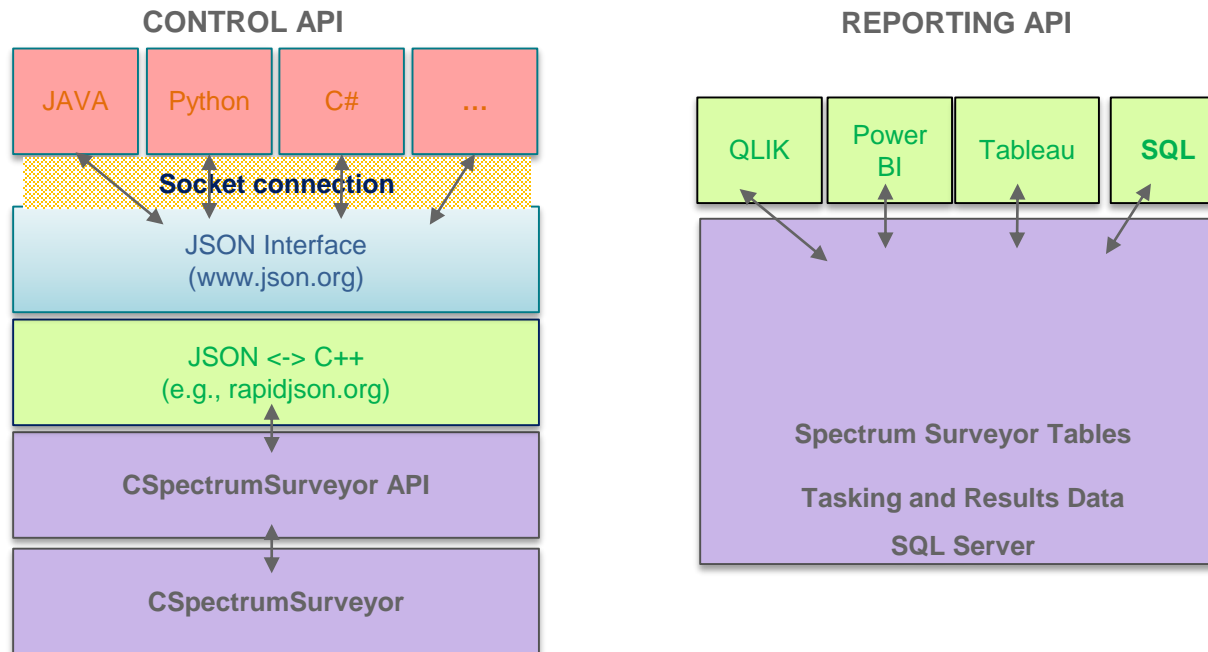
- Spectrum Surveyor includes several system integration options including:
  - Customer developed clients, both for system control and reporting
  - Integration of 3<sup>rd</sup> party systems at data level (tasking/results data)
  - Integration with commercial visualization and reporting tools

# Spectrum Surveyor Integration – System control and result analysis provided by 3<sup>rd</sup> party software



# Spectrum Surveyor Integration – System control and result analysis provided by 3<sup>rd</sup> party software

- Integration is supported by the following APIs:



# Control API Example Using Python



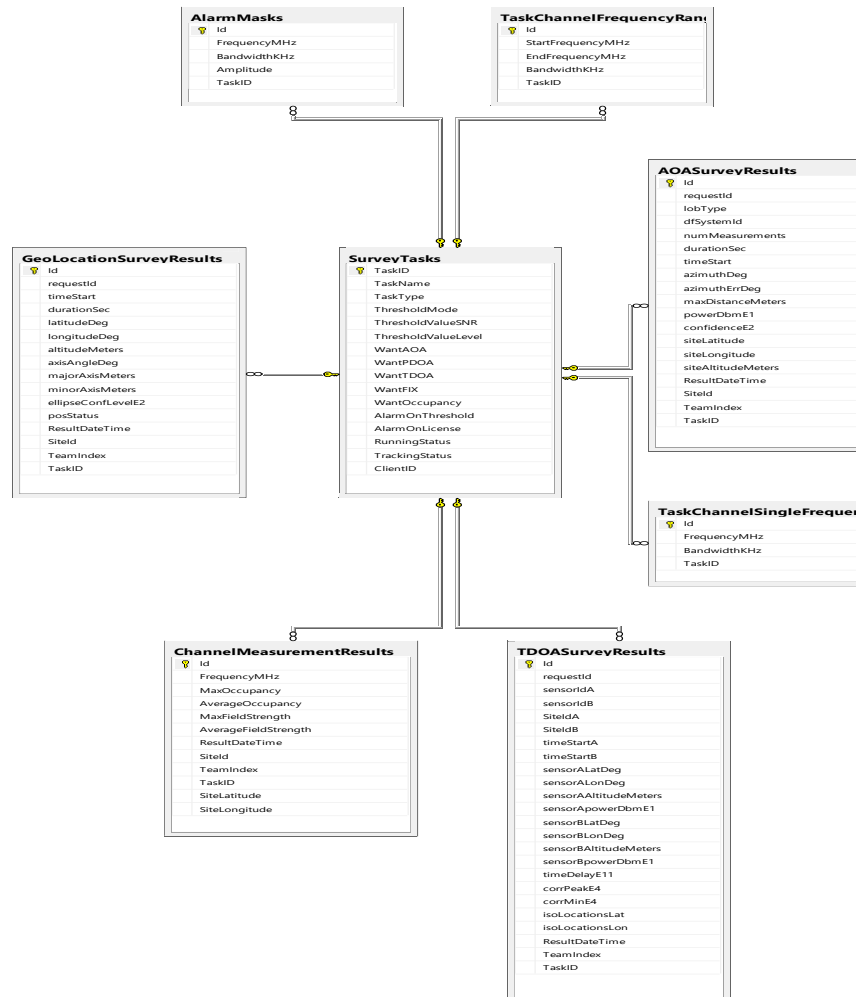
```
import socket
import json
s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
s.connect(('localhost', 3429))
s.settimeout(0.1)
def send(request):
...   global s
...   s.send((json.dumps(request)+"\n").encode())
def recv():
...   global s
...   return (json.loads(s.recv(999).decode()))
team_request = {}
team_request['category'] = 'team'
team_request['operation'] = 'create'
team_request['team name'] = 'test team'
team_request['site ids'] = [3,4,5]
send(team_request)
team_response = recv()
print(json.dumps(team_response, indent=4))
{
  "category": "team",
  "error code": 0,
  "operation": "create",
  "site ids": [],
  "team id": 101
}
```

```
task_request = {
... 'category' : 'task',
... 'operation' : 'create',
... 'type' : 'frequency band',
... 'start frequency' : '88000000',
... 'end frequency' : '108000000',
... 'bandwidth' : 200000,
... }
send(task_request)
task_response = recv()
print(json.dumps(task_response, indent=4))
{
  "category": "task",
  "error code": 0,
  "operation": "create",
  "task id" : 17
}
task_request['operation'] = 'start'
task_request['task id'] = 17
task_request['team id'] = 101
task_request['start time'] = 'now'

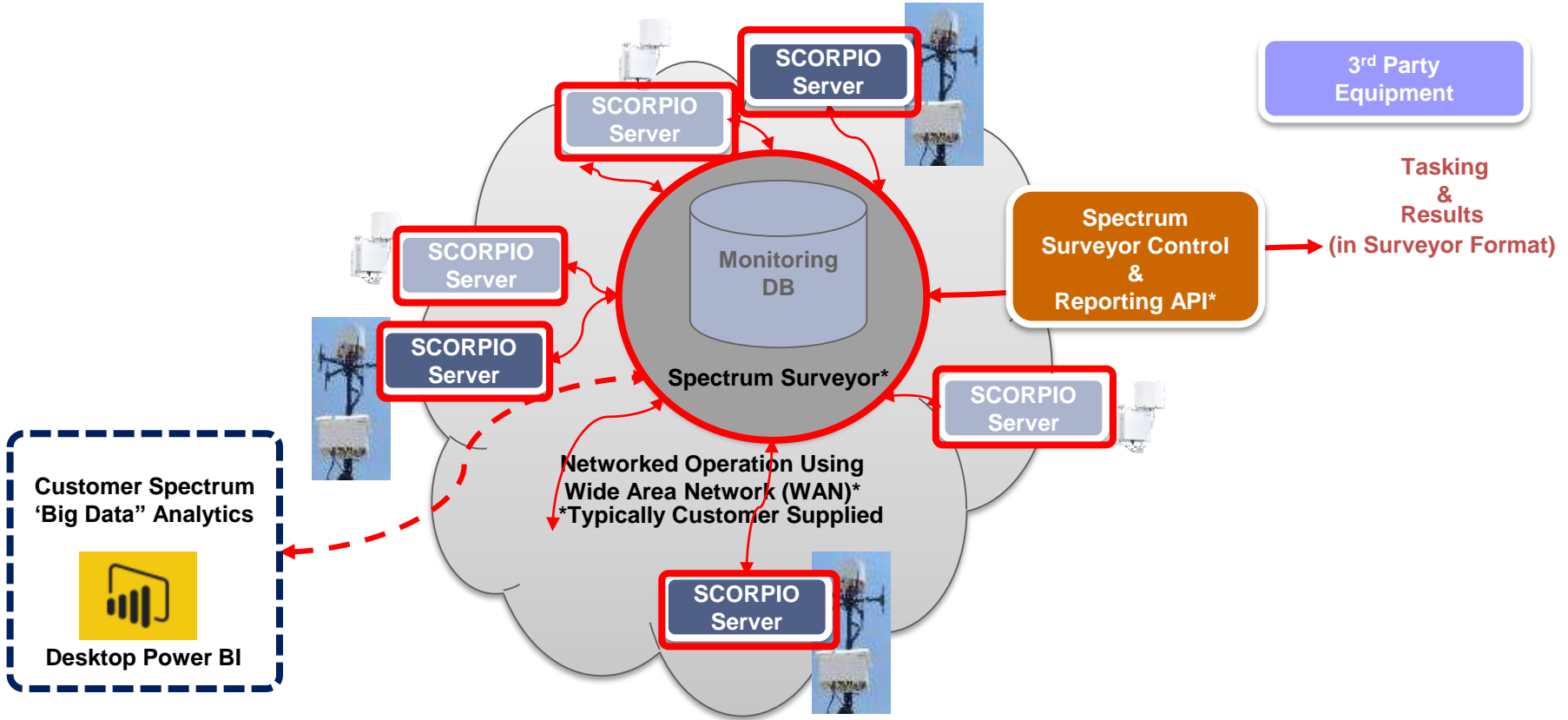
send(task_request)

task_response = recv()
print(json.dumps(task_response, indent=4))
{
  "category": "task",
  "error code": 0,
  "operation": "start",
  "task id": 17,
  "sms task": 1004
}
```

- SQL database schema
- Access to both tasking data and measurement data



# Example of Integration with 3<sup>rd</sup> Party Monitoring Systems



Monitoring Equipment  
TCI 709/707  
Mon & TDOA

SCORPIO Server

Monitoring Equipment  
TCI 709/707  
Mon & AOA & TDOA

SCORPIO Server

Client Workstation

SCORPIO Client with  
Spectrum  
Surveyor Option

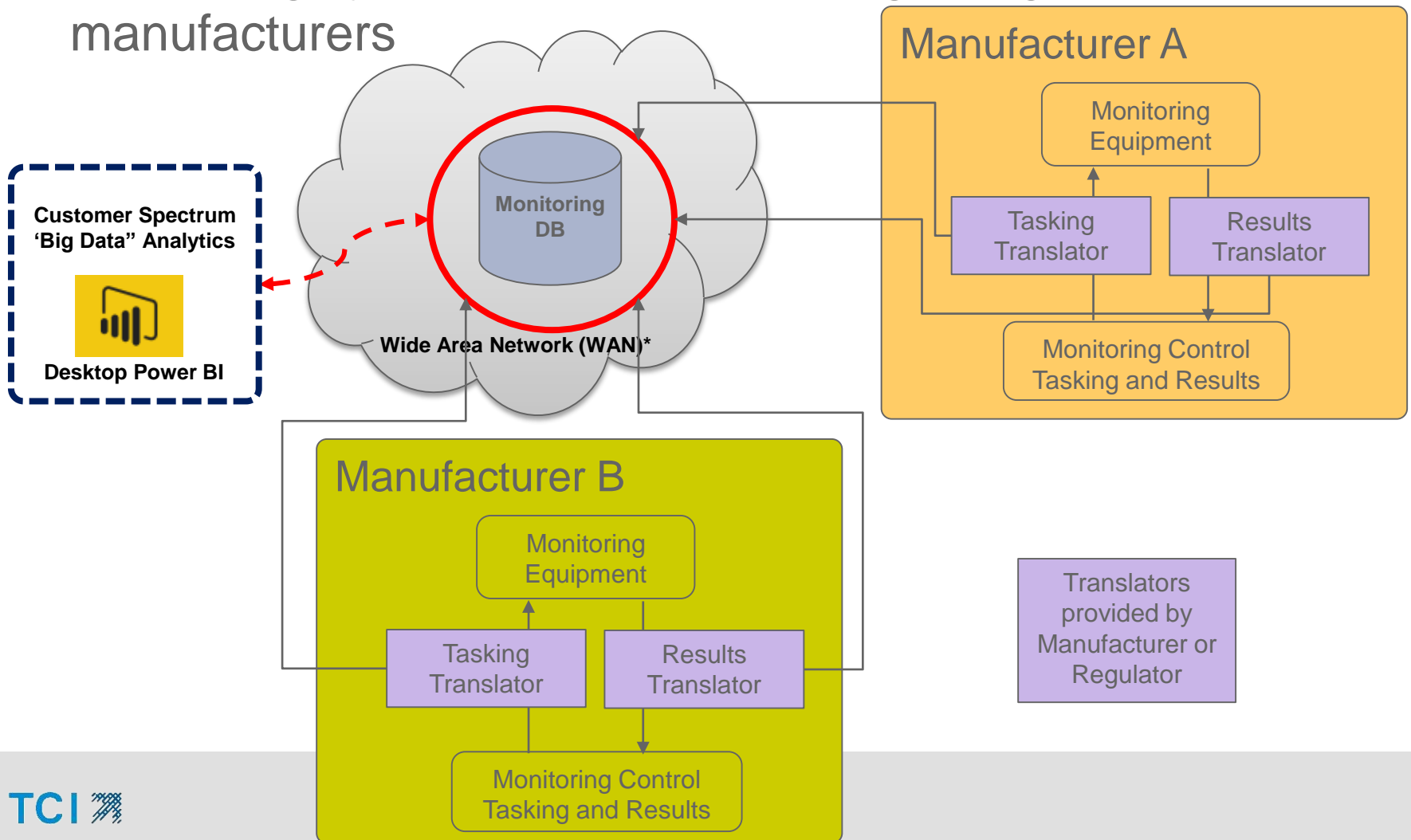
\*Spectrum Surveyor is an option for Scorpio Monitoring System

\*\*Customer can deploy spectrum analytics tools to analyze Surveyor data



# Example of Integration with 3<sup>rd</sup> Party Monitoring Systems

- Regulator is planning to expand an existing spectrum monitoring system and is considering using multiple manufacturers



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# Thank You