Review of Contemporary Spectrum Sensing Technologies

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For
IEEE-SA P1900.6 Standards Group

Authors note: This survey is provided by the author to assist the P1900.6 standards group in defining a standard interface definition for spectrum sensing technologies. The survey is provided "as is". It does not represent a product of the SDR Forum, nor does it reflect the opinions of the SDR Forum or its members. The author reserves the right to utilize the contents of this survey in other venues.

1 Introduction

Spectrum Sensing is not a new science: spectrum sensing and modulation recognition have been around for decades supporting a number of different purposes:

- Improving quality of service in wireless networks
- Detection of unauthorized transmitters for regional spectrum enforcement
- Signals Intelligence – including both Communications Intelligence (COMINT) and Electronics Intelligence (ELINT)

What is new is the desire to encapsulate the technologies traditionally associated with these purposes to allow non-primary access to unused spectrum by a licensed or unlicensed device.

The purpose of this study is to catalogue a representative sample of available spectrum sensing technologies, and then through analysis ascertain the interface features between the "sensing system" and the "cognitive engine" that are common among them. This information will act as input to the IEEE Standards Association P1900.6 Standards Group, to support defining the requirements for the 1900.6 interface standard.

2 Review Methods

This study is performed primarily through the use of secondary market research, identifying available products and vendor hardware and software technologies for finding and identifying signals by using of online search engines (i.e. Google) and the IEEE Communications Society Digital Library. The study is not exhaustive, and does not attempt to catalogue the various techniques used in detection of signals, although it is recognized that certain features in the interface between the sensor subsystem and the cognitive engine may be technique specific.

Keywords used in this search include the following:

- Spectrum Sensing/Sensor
- Spectrum Analysis/Analyzer
- Spectral Analysis/Analyzer

- Spectrum Monitoring/Monitor
- Signal Detection/Detector
- Signal Classification/Classifier
- Modulation Recognition/Recognizer

Results are catalogued into three separate categories

- Traditional Spectrum Analyzers
- Spectrum Monitoring Systems
- Signal Identification and Modulation Recognition Systems

It is important to note that, while providing a good starting point for discussion, secondary market research such as this is not a substitute for primary input from technology vendors, include vendor interviews, focus groups, and surveys.

3 Architecture Assumptions

Information on the sensor system interface was extracted during the market survey assuming the architectural model presented in Figure 1. This model assumes that four separate types of data are supported on the sensor interface:

- **Sensor Characterization Data –** This part of the sensor interface facilitates the transfer of parameters from the sensor subsystem so as to ascertain the capabilities of the sensor
- **Sensor Control Data –** This is the part of the interface used to setup and control the sensor subsystem
- **Sensor Data –** This is the primary sensor data and includes real time information on signals that have been detected and signals that have been identified
- **Recorded Data –** This is non-real time data that may include sensor logs, raw sensor data, processed sensor data

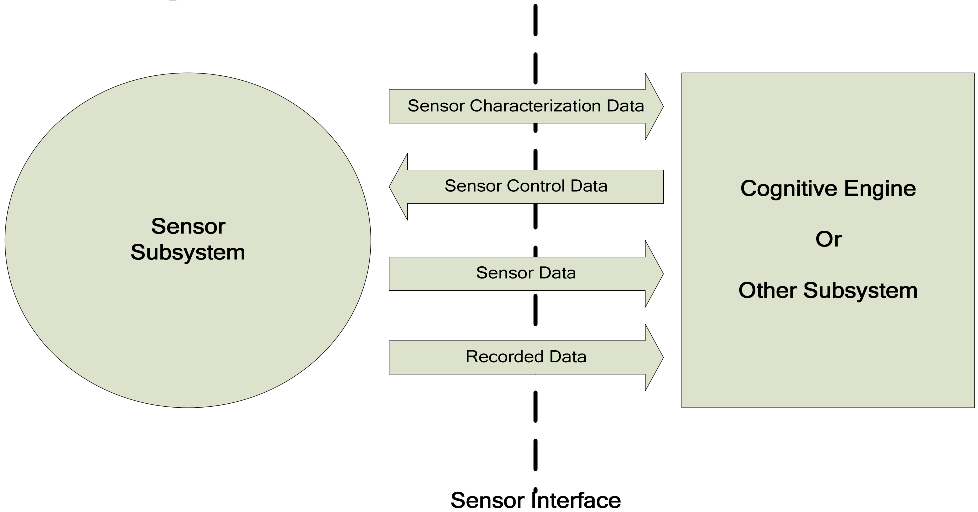

Figure 1: Architecture Assumed in Market Survey

4 Traditional Spectrum Analyzers

Tradition spectrum analyzers, coupled with a pre-selector and antenna, are often used to survey the signal environment to ascertain what frequencies are occupied. There are two basic types of systems in use today: FFT analyzers and radiometers. FFT analyzers digitize the input signals over some frequency range and then do digital FFT processing to determine the power spectral density across that range. Radiometers use an RF receiver to tune to a each frequency across a band and then measure the received signal power at each frequency. Many spectrum analyzers utilize a combination of both of these techniques to define spectral occupancy. A sampling of traditional spectrum analyzers is provided in Table 1.

Table 1: Sample of traditional spectrum analyzer systems found in market survey

Product	Company	Range	Resolution
Spectrum Master	Anritsu	9 KHz to 7.1 GHz	1 Hz to 3 MHz
FSU Spectrum Analyzer	Rohde & Schwarz	20 Hz to 67 GHz	1 Hz to 50 MHz
E4440A	Agilent	3 Hz to 26.5 GHz	10 MHz plus FFT
RSA3408B	Tektronix	DC to 8 GHz	Up to 36 MHz
Air Magnet	Air Magnet	2.4 to 2.5 GHz	.1 to 5 MHz
SR2000 Spectrum Monitor	AOR	25 MHz to 3 GHz	FFT

Specifications for these types of "sensor systems" identify the following "sensor characterization" parameters that common to all of them:

- Sensitivity
- Dynamic Range
- Frequency Stability
- Phase noise
- Amplitude Accuracy
- Sweep Time

In addition, most of these devices incorporate a selection of basic spectral averaging functions to help characterize the spectral profile of a particular band of interest. They also generally have the ability to store a spectral mask and compare against that mask with various "threshold" functions to determine when a signal enters or leaves that band, thus changing the profile. Identified signals are generally reported by "center frequency" and bandwidth, with bandwidth measured against user defined values (3dB, 6dB, 10dB, 20 dB, etc.).

5 Spectrum Monitoring Systems

Unlike traditional spectrum analyzers, whose primary purpose is for RF test and measurement, spectrum sensing systems are specifically designed to measure spectrum occupancy over time. These systems typically incorporate complex logging features use sophisticated algorithms to maximize the probability of signal detection and minimize false alarms. These systems also typically include Direction Finding capabilities to help in finding unlicensed or unintended emitters.

Table 2: Sample of spectrum monitoring systems found in market survey

Product	Company	Range	Instantaneous BW
Spectrum Explorer	CRC	2 MHz to 6 GHz	160 kHz
ARGUS-IT	Rohde & Schwarz	1 GHz to 26.5 GHz	?
Model 745	TCI	20 MHz to 3 GHz	20 MHz
T-REX	Coherent Systems	20 MHz to 18 GHz	64 MHz
RF Hawk Signal Hunter	Tektronix	10 KHz to 6.2 GHz	3 MHz
E3238 Signal Survey System	Agilent	100 KHz to 26.5 GHz	36 MHz
Skylark7050C	Grintek	1 MHz to 3 GHz	20 MHz

During this survey, a number of software products were also found that when combined with a traditional spectrum analyzer convert it to a more full featured signal monitoring system. These include products such as the MX260005A from Anritsu and Oasis from Summitek Instruments:

http://www.eu.anritsu.com/files/jan1998_a.pdf
http://www.summitekinstruments.com/oasis/

Spectrum monitoring systems generally advertise similar types of base specifications as the more traditional spectrum analyzers. In addition, these systems promote a number of additional "sensor characterization data" that are specific to the system including:

- Detection Methods/Search Modes
- Calibration Method
- Channel Filtering
- Recording Capabilities
- Location/mapping/time of day functions
- Logging functions

These systems also often employ some type of a scripting language to facilitate automated signal detection, allowing the user significant flexibility in setting up the signal detection process.

It should be noted that several of these systems reference ITU recommendations for spectrum monitoring:

- Frequency and frequency offset measurements (ITU-R SM.377)
- Field strength measurements (ITU-R SM.378)
- Bandwidth measurements (ITU-R SM.443)
- Spectrum occupancy measurements (ITU-R SM.182/ITU-R SM.328)
- Modulation depth and frequency deviation measurements (ITU-R SM.328)
- Radio direction finding and location, listening and identification in the HF (ITU-R SM.854), V/UHF and higher frequency ranges

A follow on review of these recommendations is likely important in establishing any sensor interface standard.

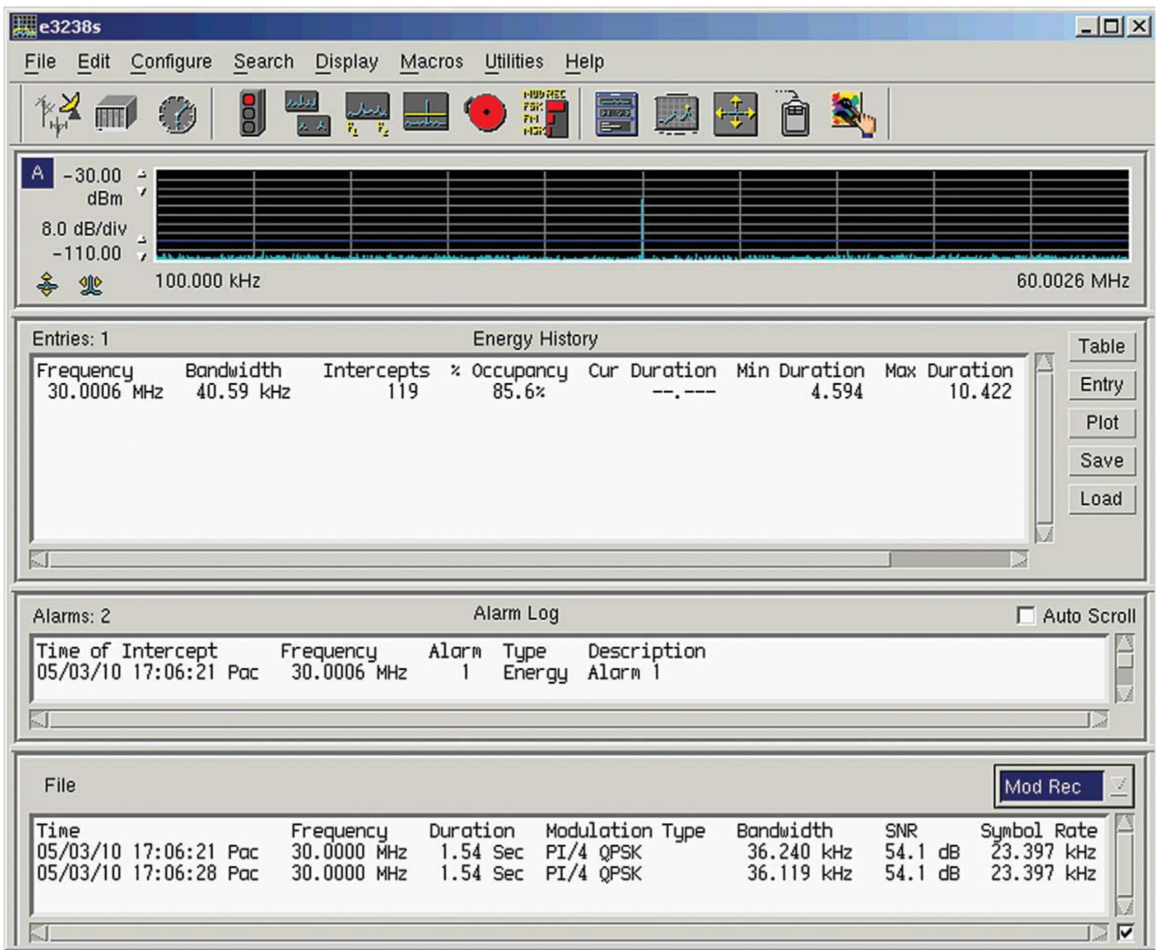

Figure 2: Screen Capture from E3238S GUI

6 Signal Identification and Modulation Recognition Systems

Many signal monitoring systems also include an ability to classify detected signals, identifying modulation structure and signal type. These types of systems generally fall into one of two categories: blind detection where the signal is identified through analysis of signal parameters (amplitude, phase and/or frequency vs. time) or a directed search, where the detected signal is compared against one or more known signal types using a matched filter algorithm or other similar technique. Products supporting these types of capabilities include the following:

Table 3: Sample of signal classification systems found in market survey

Product	Company
Communications Signal Analyzer	CRC
Shoghi Multi Channel Signal Classifier, Demodulator And Decoder System	Shoghi Communications
E3238S	Agilent
RF Hawk Signal Hunter	Tektronix
Spectrum Master	Anritsu

Specifications for these types of "sensor systems" indicate that "sensor data" typically measured in supporting signal identification includes:

- Instantaneous amplitude
- Instantaneous phase
- Instantaneous frequency
- Instantaneous BW
- SNR
- Symbol rate

Modulation types against which detected signals can be compared typically include:

- CW
- AM
- DSB-SC
- SSB
- FM
- M-ary FSK
- MSK and GMSK
- BPSK
- QPSK
- Pi/4 QPSK
- 8PSK
- 16 PSK
- 16QAM
- 32 QAM
- 64 QAM
- 128 QAM
- 256 QAM
- OOK

As with signal detection, these systems also often employ some type of a scripting language to facilitate automated signal identification. These systems also generally provide a measure of “confidence” for each proposed signal identification.

In addition, to general modulation recognition capabilities, signal identification systems often include measurement capabilities that are specific to one or more of the following types of signals:

- WCDMA/HSDPA,
- CDMA,
- EDVO,
- DVB-T/H,
- ISDB-T,
- GSM/GPRS/EDGE,
- TD-SCDMA,
- Fixed WiMAX
- Mobile WiMAX

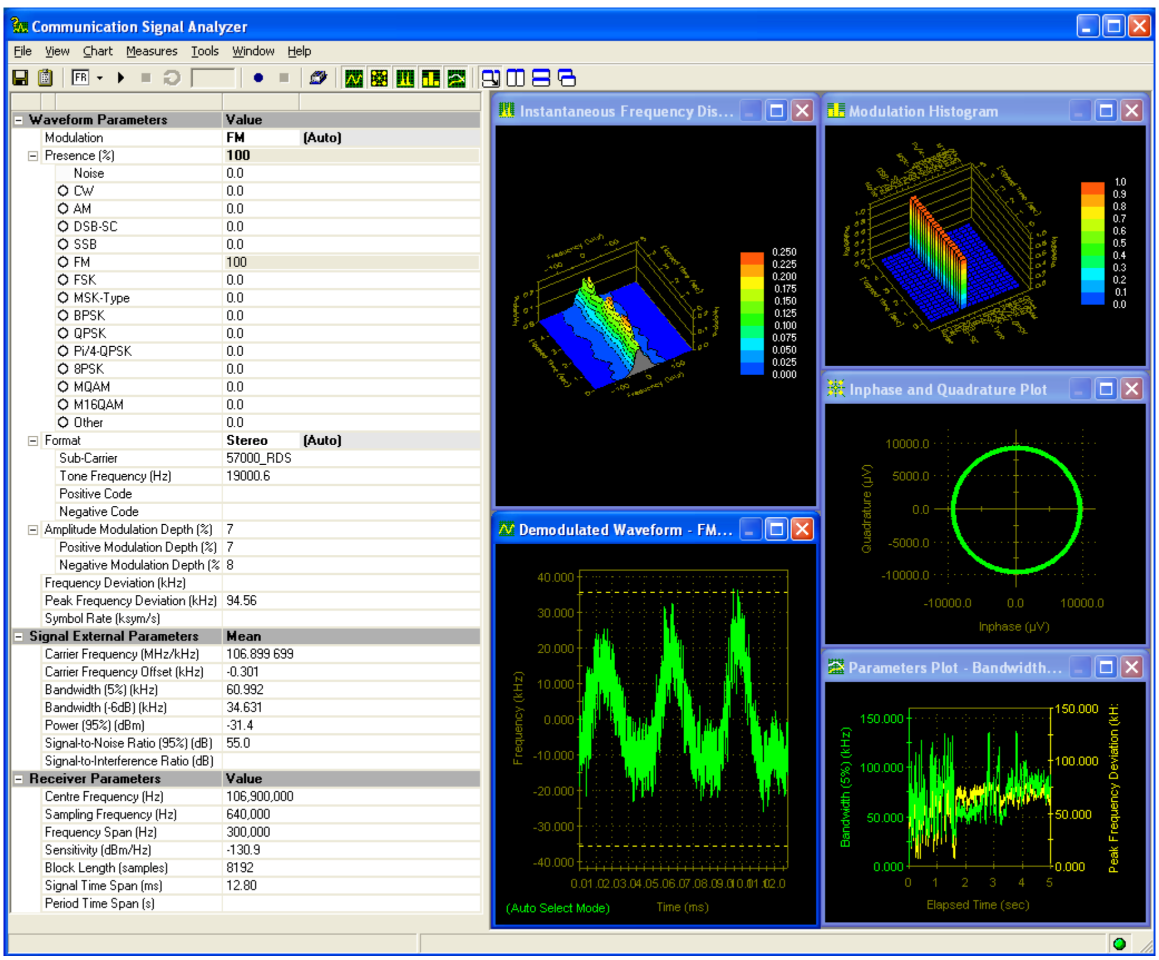

Figure 3: Screen Capture from Communications Signal Analyzer GUI

7 Analysis of Findings Impacting the Sensor Interface

In this section, common interface requirements for automated spectral sensing systems

7.1 *Sensor Characterization Data*

Analysis of the data sheets and user guides for the technologies identified in this market survey indicate the base parameters common across sensor products that may be transferred in the sensor characterization data include:

- Frequency Range
- Frequency Resolution
- Sensitivity
- Dynamic Range
- Phase Noise
- Amplitude Accuracy
- Sweep Time

Signal detection functions that may be transferred in the sensor characterization data include:

- A list of supported thresholding and alarm functions
- A list of supported averaging functions
- A list of supported time of day functions
- A list of supported geolocation functions

Sensors subsystems supporting the identification of detected signals may also include the following in their sensor characterization data:

- Directed Search – what modulation schemes and waveforms can the sensor detect
- Parametric search – what signal parameters can the sensor measure

Finally, for those sensors supporting recording function, there are a final set of sensor characterization data that must be included:

- how much raw data can the sensor capture, and what is the format of that data
- how much processed data can the sensor capture, and what is the format of that data
- What logging functions are supported

7.2 *Control Inputs to the Spectrum Sensing Subsystem*

Analysis of the data sheets and user guides for the technologies identified in this market survey indicate the following sensor control data were typical sensor products:

- Start Frequency
- Stop Frequency
- Gain

- Bandwidth
- Sweep Time
- Channel Spacing

Control data associated with signal detection functions, signal identification functions, and calibration functions appeared to be sensor specific, and additional analysis is necessary to quantify those controls. In addition, functions supporting the set-up of automated search scripts are also technologies dependent and therefore require further exploration.

7.3 Sensor Data Returned by the Spectrum Sensing Subsystem

Functions must be provided by the sensor interface to get the information on signals that have been detected from the sensor. Analysis of products evaluated in this market survey indicates that each sensor data packet should include:

- Center frequency of the detected signal
- Bandwidth of the detected signal
- Modulation type of the detected signal (optional)
- Signal type (optional)
- Time of day the signal was detected (optional)
- Signal Duration (optional)
- Sensor location when the signal was detected (optional)

7.4 Recorded Data

The sensor interface must facilitate the transfer of log files and recorded data from the sensor subsystem to include establishing protocols to facilitate the data transfer and any associated metadata (time of day, location, etc.).

8 Conclusions

A host of specifications and features relevant to the sensor interface were identified in this initial survey of available technologies. Significant follow on work is required to qualify and quantify these interface requirements for incorporation into the P1900.6 standard.