IEEE Standard for Information Technology—

Telecommunications and information exchange between systems

Wireless Regional Area Networks (WRAN)—

Specific requirements

Part 22.3: Spectrum Characterization and Occupancy Sensing

Sponsor

**LAN/MAN Standards Committee**of the
**IEEE Computer Society**

Approved Date XX

**IEEE-SA Standards Board**

Abstract: This standard specifies the architecture, abstraction layers, interfaces and metadata requirements for Spectrum Characterization and Occupancy Sensing (SCOS) system, a defines performance parameters, units and measures. This SCOS system comprises one or more semi-autonomous Spectrum Sensing Devices which scan electromagnetic spectrum, digitize it and perform processing, transmitting the resultant data with appropriate metadata to a central storage and processing system, according to rules, policies or instructions imposed on the Spectrum Sensing Devices by a management system.

Keywords: radio spectrum sensing, spectrum monitoring, signal characterization, cognitive radio, IEEE 802.22.3, WRAN standards

[[1]](#footnote-1)•

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Introduction

This standard specifies the functional elements, system architecture, abstraction layers, interfaces and metadata requirements for Spectrum Characterization and Occupancy Sensing (SCOS) system, with some limited definition of performance parameters, units and measures. It is intended to incorporate elements of existing standards and technology components to make it fast to implement using “off the shelf” hardware and software modules. The standard is intended to be flexible to make it forward-compatible as both radio sensing hardware and software technology develops, with an emphasis on using shared, virtualized, Internet-connected computing resources. The reference architecture describes one or more semi-autonomous Spectrum Sensing Devices which scan electromagnetic spectrum, digitize it and perform some level of processing, transmitting the resultant data with appropriate metadata to a Spectrum Sensing Management System. This command and control system manages scan requests from users, manages and advertises to users the scanning resources available to it from its connected Sensing Devices, and packages and forwards scan data to specified destinations according to rules, policies or instructions imposed by operator of the SCOS system.

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1. Section 5: System Definition
	1. System Roles

The following roles have been identified based on operational requirements for the SCOS system.

**Sensor Owner:** The individual or organisation that deploys and has administrative and physical control over the sensing devices (SD). SDs are typically physical devices.

**Sensing Data Administrator:** The individual or organisation that deploys and has administrative and physical control over the Data Clients consisting of data stores or other consumers of spectrum sensing data delivered by the SCOS system.

**SCOS Administrator:** The individual or organisation that deploys and has administrative and physical control over the SCOS System, consisting of the Sensing Management System and Sensing Data Manager.

**Tasking Agent:** The individual or system that authenticates with the SCOS system and causes a scan activity to be scheduled.

* 1. System Architecture

The SCOS system architecture is based on the design objective of abstracting the layers between the platform users, sensing task management, sensing data management and sensor device management in order to facilitate a flexible implementation where different areas by be implemented or operated by different organizations, but still allow inter-operation.

The SCOS system is composed of five key entities:

1. Sending Devices (SDs) that perform the sensing function.
2. Sensing Manager (SM) that schedules spectrum scan.
3. Data Manager (DM) that manages the sensing data from the sensing devices.
4. Tasking Agents (TAs) that are interested in spectrum monitoring and issue spectrum sensing tasks to the SCOS platform
5. Data Client (DC) that receive the sensing data published by the SCOS platform

Figure 1 shows the five key entities within the SCOS system.



**Figure 1: SCOS System Block Diagram.**

SCOS Manager is an aggregate entity composed of Sensing Manager and Data Manager. SCOS platform manages sensing tasks, sensing devices, and sensing data.

The SCOS Manager provides Tasking API to the Tasking Agents to initiate spectrum sensing tasks. The sensing tasks are scheduled by the SCOS platform on the sensing devices. The sensing devices send the sensing data to the SCOS platform. The SCOS platform publishes the sensing data to the Data Clients using SCOS Data Client API.

The SCOS Manager provides Sensing API and Data Collection API to the Sensing devices for the purpose of associating sensor devices with the platform, performing sensing operations, and collecting the sensing data.

Within the SCOS system, the SDs shall not communicate with each other, or directly with the user of the SCOS system (Tasking Agent).

* + 1. Topology

The SCOS system consists of a single SM and a single DM, which communicate over any standard network transport with one or more SDs.

The SM handles sensing tasks from one or more TAs. The DM publishes sensing data to one or more DCs.

Thus, the topology mapping for sensing tasks is hence N:1:N for TA:SM:SD. Similarly, the topology mapping for sensing data publishing is N:1:N for SD:DM:DC.

Figure 2 illustrates the SCOS system topology.



**Figure 2: SCOS System Topology**

* + - 1. Non 802.22.3 compliant SDs and SCOS Cascading

802.22.3 standard makes provision for proxying, that allows a non 802.22.3 compliant SD to associate with and be controlled by an SM, as well cascading of systems, where one 802.22.3 compliant SM to be associated with, and delegate tasks to, another 802.22.3 SCOS system.

SD Proxy facilitates an SM communicate with proprietary sensing hardware, acting as a software translation mechanism that translates between SCOS messages.

SM Proxy enables cascading of SCOS systems where an SM can communicate with other SMs as if they were associated SDs.

Figure 3 illustrates the extensions with an instance of system topology.



Figure 3. An SCOS System Instance with Extensions

* + 1. Entity Functions
* Tasking Agent is the entity that initiates a spectrum monitoring request to one or more Spectrum Sensing Managers (SM). Tasking Agents can be human or machine, and have various levels of privileges regarding what spectrum information collection can be initiated. Tasking Agents would determine where sensing data is to be transmitted, and authorization to access that data would rest with the owner of that data storage entity. and what spectrum information can be accessed from a Data Client.
	+ An Tasking Agent (user of the SCOS system) and SM (Sensing Manager) communicate by REST API to ask for available resources, and request a scan.
* Data Client is a data store for storing spectrum information collected from the sensing network. There can be multiple DCs that sensing data is transmitted to by the Data Manager, and these can be, but not necessarily, associated with a specific Tasking Agent.
	+ The Data Manager transmits data to the DC via a Message Queue, and the Tasking Agent interacts with the DC using their chosen mechanisms (out of scope of this standard)
* Spectrum Sensing Manager (SM or Sensing Manager) manages a collection of Spectrum Sensing Devices (SD). Requests for spectrum measurements from Tasking Agents are inserted into a scan schedule on the SM for all its attached SDs, as far as possible under a set of slot availability rules. This schedule is synched to the appropriate SDs associated with the SM. Data from the SDs are collected at the Data Manager for transmission to one or more DCs for long term storage and processing.
	+ The SM is associated with SDs (Sensing Devices) through a synchronous interface, where the SM enumerates and holds a list of available resources for each SD.
	+ The SM stores and manages a schedule of scans against the sensing resources, and synchronizes this schedule with all SDs both on a change being made and periodically to ensure correct state.
* Data Manager receives transmissions of packaged scan data from SDs, and retransmits it to one or more destinations, as defined by the policies associated with each Tasking Agent (the source of scan requests)
	+ The “Data Manager” applies any policies and then handles the Store & Forward to one or more DCs using a Message Queue or Streaming Mechanism
* The Sensing Manager and Data Manager together form the SCOS Manager, and each can be on the same platform or separate platforms.
* The Spectrum Sensing Device is the sensing hardware that collects the spectrum data requested by the SM on behalf of each Tasking Agent. The SDs may exist with various levels of sophistication. The less sophisticated might be capable of measuring only one band, at only one resolution with little on-board processing. Other sensors may incorporate sophisticated antenna techniques, multiple bands, calibration processes, on-board data processing and/or storage and/or be capable of mobile operation.
	+ An SD performs the scans in the schedule, and transmits the data and associated metadata through an asynchronous interface (message queue, or real time stream) to a “Data Manager” that performs system data validation (i.e. that a transmission is received completely, partial scans are consolidated, etc).
* SM Proxy facilitates an SM talk to another, with the downstream SM appearing as if it were an SD with a set of resources it provides. This downstream SCOS system would need to be 802.22.3 compliant.
* SD Proxy enables an SM talk to any other proprietary sensing hardware, acting as a software translation mechanism that translates between commands/metrics/etc. It would need to be custom written for the particular device it talks to.

The flow of instructions and data is described in Figure 4: SCOS Functional Block Diagram.



Figure 4: SCOS Functional Block Diagram

* 1. System Workflow

The Tasking agents interact with Sensing Manager through the 802.22.3 defined Tasking API. The tasking API facilitates querying the available sensing resources and schedule sensing tasks as permitted by resource availability, authorisation level and system policies.

The sensing devices are associated with the SCOS system using the SCOS sensing API. The SM maintains an inventory of the sensing resources along with the SD capabilities and parameters described according to this 802.22.3 standard.

Following is the typical workflow within the SCOS system.

* The Tasking Agent submits a scanning task into a schedule managed by the SM using the SCOS Tasking API defined in this 802.22.3 standard
* The SM maintains the schedule of tasks and synchronises this schedule of tasks to the SD using the SCOS sensing API defined in this 802.22.3 standard
* Within the SD, radio energy shall be collected by an antenna and transferred through an interconnect to a signal conditioner. Conditioned signal will be then transferred to a signal processing system to produce a baseband signal that can be quantised and passed in digital form to be analysed through whichever sensing technique is offered by the SD
* The data from this analysis, and the associated metadata that includes the sensing technique and environment, hardware, software and configuration parameters as defined in this standard, can be temporarily stored on the local device before it shall be transmission to an end point.
* SD transmits the sensing data to the Data Manager using the SCOS Data Collection API.
* The DM establishes the end point of data package transmissions according to the Tasking Agent’s nominated DCs, and in accordance with the policies defined in the SMS. DM publishes the data to the DCs.
* Finally, SMS reports the success or otherwise for the sensing task back to the original Tasking Agent.
	1. System Entity Models
		1. Tasking Agent

Tasking Agents are human or machine entities that can query SCOS resources and request scans to be performed.

There are at least three main classes of consumers of spectrum data:

**Type A Agent:** are specifically looking for current sensing information, and request specific scans to obtain specific data (e.g. law enforcement).

**Type B Agent:** have a requirement to keep spectrum information up to date (e.g. spectrum occupancy database operators), and will need to request periodic scans to achieve this.

**Type C Agent:** those that want to read spectrum information from a DC that is already populated with their required data. These users are not contemplated in this standard.

In general, it should be assumed that a Type A Tasking Agent would have higher priority in terms of scan resources, as governed by a Policy expanded on below.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: TA Name DATA TYPE: string | Required | The name of the tasking agent registered with SCOS operator.The maximum length is 64 octets. |
| NAME: SCOS Administrator DATA TYPE: string | Required | The name of the SCOS operator.The maximum length is 64 octets. |
| NAME: TA type DATA TYPE: string | Required | The type of TA. The maximum length is 64 octets. |
| NAME: TA ID DATA TYPE: string | Required | The unique ID assigned to the tasking agent. The maximum length is 64 octets. |

* + 1. Spectrum Sensing Device (SD)

SDs convert radiative electromagnetic energy into a voltage, which is then sampled. The samples can then be processed in various ways to provide information on the immediate RF environment, e.g., amplitude statistics versus frequency, amplitude and phase versus time at a given frequency, occupancy statistics, angle of arrival.

* + - 1. Hardware Model

A simplified hardware block diagram of a general SD model is depicted in 5. SD hardware designs are not required to have each component shown in the block diagram. Specifics for each component (e.g., presence, model, operational parameters), however, is required metadata when SD capabilities are queried by the SM. This SD definition metadata is also accompanied with the output data messages.



Figure 5: SD Simplified Hardware Model Block Diagram

The SD is composed of the following functional elements, as follows:

* Functional element 1 – Antenna: An antenna used to collect RF energy. This is fed to functional element 2 over a hardware interface (interconnect cable)
* Functional element 2 – Signal Conditioning Unit: An RF front end unit consisting of (all or some of) an RF switch (optional, with the ability to accept an optional calibration signal), filter, Low Noise Amplifier, mixer. This sends the conditioned signal to functional element 3 over an analogue hardware interface (interconnect cable/track).
* Functional element 3 – Signal Extraction Unit: Analogue Digital Converter, spectrum analyser or Software Defined Radio to act as a baseband processor, performing a demodulation of the conditioned signal and acquires the baseband signal. This sends a digitised signal over a digital interface (interconnect)
* Functional element 4 – Compute Platform: that provides
	+ A signal processing function with a signal detection and/or classification algorithm. It sends detection/classification data to metadata consolidation and packaging function over a software interface.
	+ A metadata consolidation and data packaging function that combines sensing data with environmental inputs (where implemented), hardware, operating and system-configured metadata. It sends data packages to the transmission system over a software interface.
	+ A transmission unit that transmits scan data to the destination system over a best-effort IP connection.

The Compute Platform sends necessary command and control signals to Functional element 2 (Conditioning Unit) and Functional element 3 (Extraction Unit). It receives data from the Sensor/SDR, and polls any environment sensor input devices for necessary metadata items, such as GPS location. Interaction of the various elements is described in Figure 6: SD Functional Elements.

 

Figure 6: SD Functional Elements

This block diagram can be split into the hardware layer and the software processes that run alongside. These hardware blocks or software services generate metadata that is associated with each item.



Figure 5: SD model - Hardware layer components and Software layer processes with relevant metadata

Following table enumerates the parameter definition object for Functional element 1.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |
| NAME: ElevationBeamDir DATA TYPE: number | Required | The current angle between the horizontal plane and the line of sight, measured in the vertical plane. |
| NAME: MinAziBeamDir DATA TYPE: number | Required | The minimum azimuth beam direction.  |
| NAME: MaxAziBeamDir DATA TYPE: number | Required | The maximum azimuth beam direction.  |
| NAME: MinEleBeamDir DATA TYPE: number | Required | The minimum elevation beam direction.  |
| NAME: MaxEleBeamDir DATA TYPE: number | Required | The maximum elevation beam direction.  |
| NAME: Antenna model DATA TYPE: string | Required | The antenna model (#What are the options?). The maximum length is 64 octets. |
| NAME: Antenna type DATA TYPE: string | Required | The antenna type (#What are the options?). The maximum length is 64 octets. |
| NAME: FreqRangeMin DATA TYPE: number | Required | The lowest frequency  |
| NAME: FreqRangeMax DATA TYPE: number | Required | The highest frequency.  |
| NAME: Gain DATA TYPE: number | Required | The boresight gain.  |
| NAME: Height DATA TYPE: number | Required | The height in meters.  |
| NAME: Polarization DATA TYPE: number | Required | The polarization in degrees.  |
| NAME: HorzBeamWidth DATA TYPE: number | Required | The horizontal beamwidth in degrees.  |
| NAME: VertBeamWidth DATA TYPE: number | Required | The vertical beamwidth in degrees.  |
| NAME: CableLoss DATA TYPE: number | Required | The cable loss in dB.  |

Following table enumerates the parameter definition object for Functional element 2.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |

Following table enumerates the parameter definition object for Functional element 3.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |

Following table enumerates the parameter definition object for Functional element 4.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |

Following table enumerates the parameter definition object for Functional element 5.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |

* + - 1. SD Calibration Model

A calibration can be done in the lab at build/commissioning time, and stored as a calibration file on the SD. Further, an SD with a self-calibration capability can be instructed through an administrative interface (not Tasking Agent request) to perform a calibration using a local calibration source.

Following table enumerates the parameter definition object for SD Calibration Model.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AziBeamDir DATA TYPE: number | Required | Current boresight direction of the horizontal plane of the antenna in degrees with respect to true north. The value of this parameter is an integer with a value between 0 and 359 inclusive. A value of 0 degrees means true north; a value of 90 degrees means east. |

* + - 1. SD Algorithm Model

The algorithm model is described in terms of

* inputs into black box: the identity of the USER and SM requesting the scan, the measurement parameters, which algorithm is to be used; and
* outputs from the black box: the identity of the USER and SM requesting the scan, the requested scan parameters, the identification of the algorithm model, and the processed results.

Following table enumerates the parameter definition object for algorithmModel.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: AlgorithmSetDATA TYPE: Array of String | Required | Names of algorithms supported by the SD.The maximum length of the ID string is 64 octets. |

Following algorithms can be specified. At least once algorithm model needs to be supported by SD. Support for GenericEnergyDetection is normative.

|  |  |
| --- | --- |
| Scan Algorithm  | Description |
| GenericEnerrgyDetection | Normative. |
| CyclicFeatureDetection |  |
| CustomScanAlgorithm |  |

The standard would allow development of advanced algorithms. For example, direction finding.

It is the responsibility of the ~~SM operator~~SCOS Administrator to publish algorithm definitions externally. The implementation does not need to be publicly accessible.

[#Message]

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: TA IDDATA TYPE: String | Required | The TA ID.The maximum length of the ID string is 64 octets. |
| NAME: SM IDDATA TYPE: String | Required | The SM ID.The maximum length of the ID string is 64 octets. |
| NAME: SDScanParam DATA TYPE: Object of type SDScanParam | Required | The scan parameters object. |
| NAME: AlgorithmDATA TYPE: String | Required | The SM ID.The maximum length of the ID string is 64 octets. |

* + 1. Spectrum Sensing Manager (SM)

Following table enumerates sensing manager parameters.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: SMIDDATA TYPE: String | Required | Unique ID for the Sensing Manager.The maximum length of the ID string is 64 octets. |
| NAME: SMSIDDATA TYPE: String | Required | Unique ID for the SMS.The maximum length of the ID string is 64 octets. |
| NAME: SCOS OperatorDATA TYPE: String | Required | The registered name of the SCOS operator.The maximum length of the ID string is 64 octets. |

* + - 1. SM Association

SMs receive and manage association and disassociation requests from SDs. The details of the association and disassociation message objects are covered in Procedures Section, subsection 7.2.1

* + - 1. SM Task Scheduling

Scheduling is defined in terms of scan intervals that take up slots in a calendar schedule. These slots will include slots for long scans; and slots for very short scans to ensure fair allocation of scan resources.

Scheduling requests from a USER will be defined in terms of duration, time, repetition, etc, as well as a flag to indicate whether the desired scan slots are “Exact Time” slots or “Nearest Time” slots. The scheduler on the SM will use this to try meet the USER request (and either confirm the scan schedule is accepted or refused).

Following table enumerates the parameter definition object for scanTask.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: TaskIDDATA TYPE: String | Required | Unique ID for the Spectrum Scan.The maximum length of the ID string is 64 octets. |
| NAME: TaskDurationDATA TYPE: number | Required | Duration of scan in milliseconds. |
| NAME: TaskStartTimeDATA TYPE: Time | Required | The start time for the task. |
| NAME: TaskRepeatIntervalDATA TYPE: Number | Optional | The interval in seconds after which the task needs to be repeated.  |
| NAME: TaskRepeatCountDATA TYPE: Number | Optional | The number of times the task needs to be repeated.The maximum length of the ID string is 64 octets. |
| NAME: TaskEndTimeDATA TYPE: Time | Optional | The end time for the task. |

* + 1. Data Manager

The following table enumerates the parameter definition object for DataManager.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: DMIDDATA TYPE: String | Required | Unique ID for the Data Manager.The maximum length of the ID string is 64 octets. |
| NAME: SMSIDDATA TYPE: String | Required | Unique ID for the SMS.The maximum length of the ID string is 64 octets. |
| NAME: SCOS OperatorDATA TYPE: String | Required | The registered name of the SCOS operator.The maximum length of the ID string is 64 octets. |

* + 1. SD Proxy

[#AddDesc]



Figure 6: SD Proxy

The following table specifies the parameter definition object for SDProxy.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: SDIDDATA TYPE: String | Required | Unique ID for the SD.The maximum length of the ID string is 64 octets. |
| NAME: SMSIDDATA TYPE: String | Required | Unique ID of the SMS to which SD is associated.The maximum length of the ID string is 64 octets. |
| NAME: SCOS OperatorDATA TYPE: String | Required | The registered name of the SCOS operator.The maximum length of the ID string is 64 octets. |

* + 1. SM Proxy

[#AddDesc]

****

Figure 7: SM Proxy

The following table specifies the parameter definition object for SMProxy.

|  |  |  |
| --- | --- | --- |
| Parameter | R/O/C | Description |
| NAME: SMIDDATA TYPE: String | Required | Unique ID for the SM.The maximum length of the ID string is 64 octets. |
| NAME: SMSIDDATA TYPE: String | Required | Unique ID of the SMS to which SD is associated.The maximum length of the ID string is 64 octets. |
| NAME: SCOS OperatorDATA TYPE: String | Required | The registered name of the SCOS operator.The maximum length of the ID string is 64 octets. |

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**PDF: ISBN 978-0-7381-6723-7 STD97146**

**Print: ISBN 978-0-7381-6724-4 STDPD97146**

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