LCSM Node Based on Geo Location Spectrum Database for Cooperative Dynamic Spectrum Access

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Abstract— **This paper overviews a designed Low-Cost Spectrum Monitoring (LCSM) node that is installed in universities around South Africa. LCSM node is an electronic device that automatically monitors the frequency spectrum and then communicates the results wirelessly to the spectrum sensing enabled Geo Location Spectrum Database. The node is equipped with Wi-Fi Access Point (AP), OpenVPN client, and Application Programmable Interface (API) that encapsulates data using JavaScript Object Notation (JSON) and for being controlled remotely. LCSM nodes are designed, tested, and assembled in the lab at the Council for Scientific and Industrial Research (CSIR) before the installations at the universities. LCSM nodes have the main components such as LimeSDR, RF Splitter combiner, HiKey970, enclosure, RF cables, and antennas. Sections in this paper will explain how the LCSM nodes operate and take measurements. The measurements were taken from Television band 470MHz – 694MHz.**

Keywords—LCSM, Wi-Fi AP, LimeSDR, HiKey970, RF splitter, JSON, OpenVPN client

I. INTRODUCTION

Spectrum monitoring is an important concept for wireless communication networks, it can assist to protect the primary users of the spectrum from interference and in general monitoring how the spectrum is being used. With the increase in wireless communication technologies, the demand for broadband access also increases, therefore, it is important to know which frequency bands are being used and which are not being used. This can help with enforcing and safeguarding the regulations as well as mitigating the number of interferences experienced by different spectrum users.

In this paper, we present a Low-Cost Spectrum Monitoring node developed at the CSIR in Pretoria, South Africa. The node monitors the frequency spectrum in the Television white spaces band (470 MHz – 694MHz). With the ongoing migration from Analog to Digital broadcasting in South Africa there is a high demand for spectrum use, this device helps in monitoring and identifying the underused or unused channels for the Geo-

Location Spectrum Database (GLSD). GLSD [1] is a real-time technology that communicates with the LCSM node and shows scans and channels of the frequency spectrum which are currently available for use. The information from the GLSD makes it easier to have a cooperative Dynamic Spectrum Access (DSA) around South Africa.

Dynamic Spectrum Access (DSA) is a technology used to improve the performance of wireless communication networks [3]. The technology takes advantage of its artificial intelligence capability to efficiently utilize the spectrum by opportunistically transmitting on unused or underused frequency white spaces. GLSD will use the results from the LCSM to update its database. The GLSD captures information such as location, signal strength, frequency channel in use, etc. From the primary users of the spectrum, and every time a device is going to use the spectrum it has to register with the GLSD, meaning it will assign it to the unused information while it stores its data pending successful use of the spectrum [4] and [5]. This ensures that the devices communicating on the spectrum will not introduce any interference to the licensed primary users of the spectrum.

II. OVERVIEW OF THE LCSM AS A LINK FOR GLSD DSA

This work is a continuation of the work in progress for the development of a nationwide research platform for spectrum monitoring [1]. The aim is to improve the accuracy and the speed of the GLSD decision-making when leasing spectrum to secondary users by providing it with real-time spectrum utilization data. Incorporating spectrum monitoring to improve the DSA of the GLSD becomes a realizable goal. If this is not done the GLSD might be working with outdated data as its data is loaded once in a while and this can lead to interference for critical spectrum users [1], [2].

Spectrum prediction modeling is the main reason for the development of commands used for controlling the LCSM node remotely using the developed web interface. To accurately predict TVWS, a spectrum sensing and monitoring system had to be employed; this worked alongside a database so that smart and precise algorithms are designed from the patterns saved. This project offers a tool to help predict the availability of TVWS. The system is divided into three portions: an equipment setup to measure TV signals, GLSD to show the locations of the installed LCSM nodes, and a database for the storage of the measured data. The measurement setup is composed of three Yagi/Digital TV antennas to physically scan a band of frequencies in the UHF/VHF range, software-defined radio

(LimeSDR) receiver to select frequencies in the range of 470MHz-694MHz, a HiKey970 board to control the operations of the LimeSDR module and to temporarily store the data collected, basically acting as the server. The information obtained is displayed on the Web interface for visualization purposes. The whole equipment was powered by a 12V, 2.4A Power over Ethernet (PoE) power module.

The Platform infrastructure for spectrum monitoring encompasses different components to complete the system. As depicted in *Figure 1*, the architecture is grouped into two parts: The infrastructure/components located at the universities and the components located at the CSIR. The LCSM nodes are deployed at different Universities around South Africa. The nodes scan the spectrum and communicate the results to the MQTT Broker via the internet. The broker relays the data to the Spectrum Sensing enabled GLSD (SSEG) which processes the data and saves it to the Database. Additionally, SSEG also makes use of the server disk to save log files, scripts, and commands. SSEG GLSD makes use of the Calculation Engine, which implements some propagation models and performs calculations of the spectrum on request. The SSEG exposes the web interface or web Graphical User Interface (GUI) to the user on their machines to interact with the LCSM nodes. Each component is described in detail below:

Descriptions of the key components of the Low-Cost Spectrum monitoring Infrastructure
:
- Yagi/Digital TV antennas were mostly used in this project their function is to receive signals from different polarities, each LCSM node has three antennas to form one omnidirectional antenna.
- Message Queuing Telemetry Transport broker, MQTT broker is a server that receives all messages from the clients and then routes the messages to the appropriate destination clients. An MQTT client is any device (from a microcontroller up to a full-fledged server) that runs an MQTT library and connects to an MQTT broker over a network. In this project, the LCSM node has an installed MQTT client to connect to the MQTT broker for subscribing and publishing scanned data.
- A GLSD knows the location and parameters of the primary user's transmitters whose signals need to be protected. With the knowledge of the landscape topology and by applying complex propagation models, the GLSD [3] in this project is used to calculate the field strength at a given location.
- CSIR database for data storage, the data was stored for allowing participating partners to share and process the data. From the Web portal, participating partners can retrieve data for their studies and it can also be collected using a USB flash drive from the server administrator [4].
- The Web interface displays the properties of the LCSM node such as detector, end frequency, start frequency, sample rate, bandwidth, and the time LCSM node last published to the server [5]. Also displays the location where the LCSM nodes were installed using GLSD and

sensor ID's or the name of the sensor installed at that particular location. The Web interface also displays the processed raw data in a tabular form showing the amplitude of the spectrum in dBm, and its corresponding frequency in MHz, and lastly the Web interface displays the graphical representation of the raw data. This graphical representation is of utmost importance for the spectrum prediction model as it allows the user to save the data and analyze it remotely.

Although we present in detail the LCSM architecture. The main focus of this paper is the LCSM node, in the subsequent sections, we expand on the components of the LCSM node.
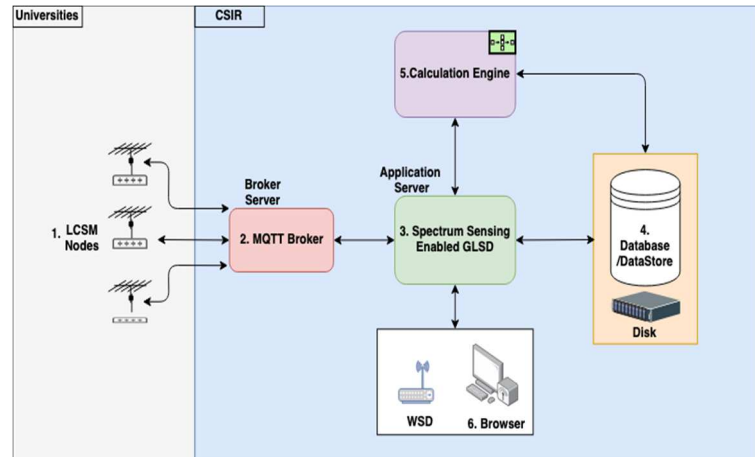

Figure 1: Architecture for Nation-Wide Low-Cost Spectrum Monitoring infrastructure.

III. OVERVIEW OF HARDWARE COMPONENTS AND SOFTWARE MODULES IN CONSTRUCTING THE LCSM NODE

In this section, we will highlight the hardware components and software modules used for the design of the node. The LCSM node is a high extent and high-density node, which is the type of node required for localized processes of determining available spectrum to avoid false positives [1]. The LCSM node is a custom-made device designed and assembled at the CSIR and deployed in different Universities around South Africa. It consists of the following components functioning collectively as shown in *Figure 2* below:
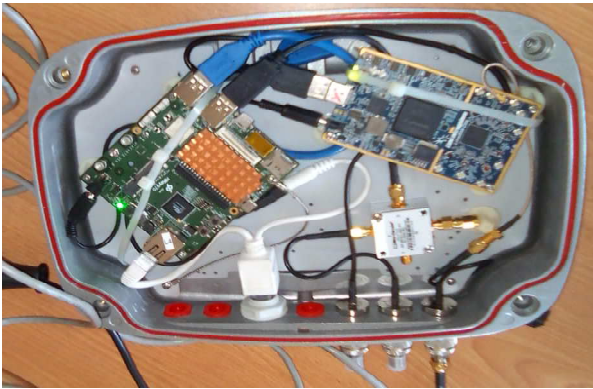
Figure 2: LCSM Node

a) **HiKey970** responsible for driving and supplying power to the LimeSDR.
b) **LimeSDR** responsible for scanning frequency bands in the wireless spectrum.
c) **Power Splitter** supplies power and network to HiKey970 and LimeSDR
d) **RF splitter combiner** takes three received signals from the three (3) antennas and combines them in one source and the source takes it to the port receiver of the LimeSDR.
e) **USB 3.0** is connected from HiKey970 to LimeSDR for communication.
f) **RF adapters** for connecting RF cables from the three antennas.
g) **Power over Ethernet cable (PoE)** carries power and internet connection to a power splitter, provides 12V, 2.4A PoE power module.
h) **A weatherproof box** secures all components inside from any external conditions such as rain, wind, and sunlight.

Software modules employed:

The node is built on the GNU Radio software platform. GNU Radio [2] is an open-source software used to create signal processing block which forms a Software Defined Radio (SDR). It is used in this device to create low-cost spectrum monitoring. The signal processing blocks for the spectrum analyzer were written in Python programming language and are running on the Ubuntu based lightweight Linux distribution Lubuntu. This is due to the size of the hardware and the processing speed of the development board used to install the SDR radio.

This software was chosen as opposed to others because of its free-for-use policy and ability to create any type of radio, as opposed to the other software platforms such as [7]SDR-J, SDR Daemon, etc. which focus only on one functionality of signal processing.

IV. LCSM EXPERIMENT SETUP OVERVIEW

Before the LCSM nodes are dispatched and deployed at the Universities they have to be configured and thoroughly tested on the expected functions and outputs. Therefore, we conducted the necessary experiments to verify the assembled nodes. The lab experiment setup is depicted in *Figure 3*
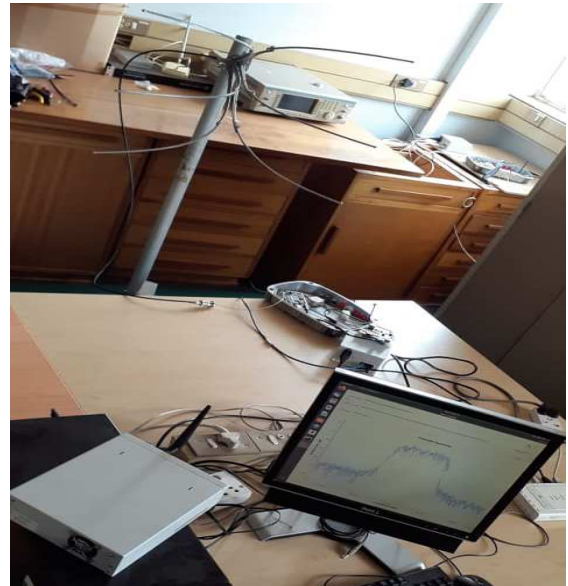

Figure 3: Lab experiment test setup

The lab experiment is divided into test procedures accordingly as follows:

- Testing of the LCSM node, hardware, and software
- Wi-Fi Connectivity
- OpenVPN
- Actuation, remote controlling, or downlink commands
- Communication of results to the SSEG

1. *Setup for Hardware and Software testing of the LCSM node:*
   - The three Yagi or Digital TV antennas must face 120 degrees each to form a 360 degrees forming complete omnidirectional antenna, and they must be 0.5m apart.
   - Ensure that all components fit in the white box enclosure.
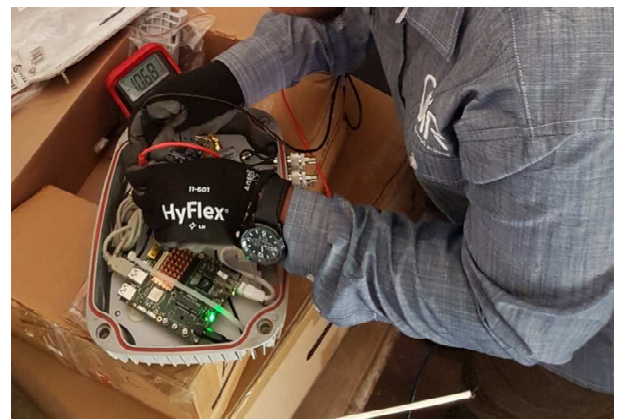   - Ensure that the power module meets the specifications of both LimeSDR and HiKey970.

Figure 4: Testing the voltage levels using Digital Multimeter

- Make sure that HiKey970 is communicating with LimeSDR through USB 3.0 protocol.
- Ensure that the LCSM node can publish scans to the server by using the MQTT protocol.
- HiKey970 must have enough space for internal data storage.

All the steps followed correctly the LCSM node must show at least analog TV or digital TV signals, for that a portable TV test receiver was used to display what is scanned on the spectrum.

2. *Wi-Fi AP and OpenVPN client testing:*
   - Installed Ubuntu 18.04 operating system on the HiKey970 board.
   - Configured HiKey970 board and tested its Wi-Fi module.
   - Installed all packages and drivers required to run the access point and OpenVPN.
   - The credentials for Wi-Fi AP and OpenVPN client are provided before accessing the device.
   - Test that the Wi-Fi start-up when HiKey970 boots up using system control libraries and tested if it's working as expected.


```
shunya@hikey970fwnlab1:~$ iw wlan0 info
Interface wlan0
        ifindex 5
        wdev 0x1
        addr c8:df:84:4e:1d:61
        type AP
        wiphy 0
```

Figure 5: Testing Wi-Fi AP using Linux terminal

- By typing ifconfig 'tun0' in the terminal as shown in *Figure 6* we checked if OpenVPN is running.


```
tun0      Link encap:UNSPEC  HWaddr 00-00-00-00-00-00-00-00-00-
          inet addr:10.8.0.14  P-t-P:10.8.0.13  Mask:255.255.25
          UP POINTOPOINT RUNNING NOARP MULTICAST  MTU:1500  Met
          RX packets:36 errors:0 dropped:0 overruns:0 frame:0
          TX packets:50 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:100
          RX bytes:4405 (4.4 KB)  TX bytes:14605 (14.6 KB)
```

Figure 6: Testing OpenVPN client on a Linux terminal

3. *LCSM node actuation:*
One of the requirements is for the actuation of the LCSM node remotely from the Spectrum Sensing Enabled GLSD web interface. The commands that are implemented currently are:
   - Scan Info – This downlink command request the current scanning information of the node.
   - Sensor Info – This downlink command request Information about the sensor.
   - System – This downlink command control the node

V. PERFORMANCE MEASUREMENTS METHODOLOGY AND RESULTS

Hardware and Software testing for the LCSM node. In this test case, the node was assembled, all the components were connected and tested for their functionality as shown in *Figure 3*. The LCSM was used to scan the TV signal and connected to the GNU Radio as depicted in *Figure 7*(left), the signal shows a peak where the TV signal is detected, to see the picture on the TV signal we used the TV test receiver as shown in *Figure 7*(Right). In this test, we were able to assemble the LCSM node and use it to scan the spectrum.

Figure 7: (Left) Digital TV signal scanned on channel 58 by the LCSM node and (Right) TV test receiver also on the same channel

For the Wi-Fi module testing or Wi-Fi connectivity testing and the OpenVPN testing, the LCSM node was configured as discussed in the previous section, we tested if the Wi-Fi module starts when the device boots up,

Figure 8: Wi-Fi AP start-up

Moreover, as shown in *Figure 8* the Wi-Fi service started correctly and we used the steps shown in *Figure 9* to connect to the device and once the device is up, we can connect to its Wi-Fi AP by providing the device Wi-Fi SSID together with the password. Additionally, we can connect to it using the ssh client, this is important when configuring the node.

Step 1: Connect to WiFi access point

SSID: "Hikey"

WiFi password: 12345678

Step 2: Connect over ssh with X forwarding

ssh -X shunya@192.168.150.4|

password: #LCSM123

Figure 9: Wi-Fi AP mode credentials

The OpenVPN client was also configured and a private connection between the LCSM node and server for remote configurations purposes.

The password for the OpenVPN client was created inside the file, by running the command shown below which then automatically runs and connects to the OpenVPN server.

```
sudo openvpn –config/home/shunya/ofcommirror.ovpn –askpass/etc/openvpn/ovpn.pas
```

```
mosquitto_pub /lcsa/scans/specscan3.json spectrum/sensing/up
['mosquitto_pub', '-h', 'spectrumbroker.meraka.csir.co.za', '-p', '1883', '-t', 'spectr
File publish output:  b"Client mosqpub/9468-hikey970 sending CONNECT\nClient mosqpub/94
. (478860 bytes))\nClient mosqpub/9469-hikey970 sending DISCONNECT\n" None
Successful publish .. now deleting file
Publishing file: /lcsa/scans/.specscan1.json.swp
mosquitto_pub /lcsa/scans/.specscan1.json.swp spectrum/sensing/up
['mosquitto_pub', '-h', 'spectrumbroker.meraka.csir.co.za', '-p', '1883', '-t', 'spectr
File publish output:  b"Client mosqpub/9469-hikey970 sending CONNECT\nClient mosqpub/94
. (1024 bytes))\nClient mosqpub/9469-hikey970 sending DISCONNECT\n" None
Successful publish .. now deleting file

Scan Interval requested: 180
Spectrum scan time elapsed: 103
Addtional sleeping required: 77
Sleeping ....
```

Figure 10: LCSM communicating through MQTT Broker

Figure 10 shows the MQTT message logs from the LCSM node. The node publishes the JSON file containing the scan results from the LCSM node. The data is temporally stored in the HiKey970 directory as shown in figure 10 by looking at line number one. LCSM node was publishing every 180 seconds to the server.

The actuation implementation on the SSEG web interface is implemented as appears in *Figure 1*, and the commands were sent and the device was able to receive the downlink commands and actuated. We were able to reboot the node and also execute the scan command.
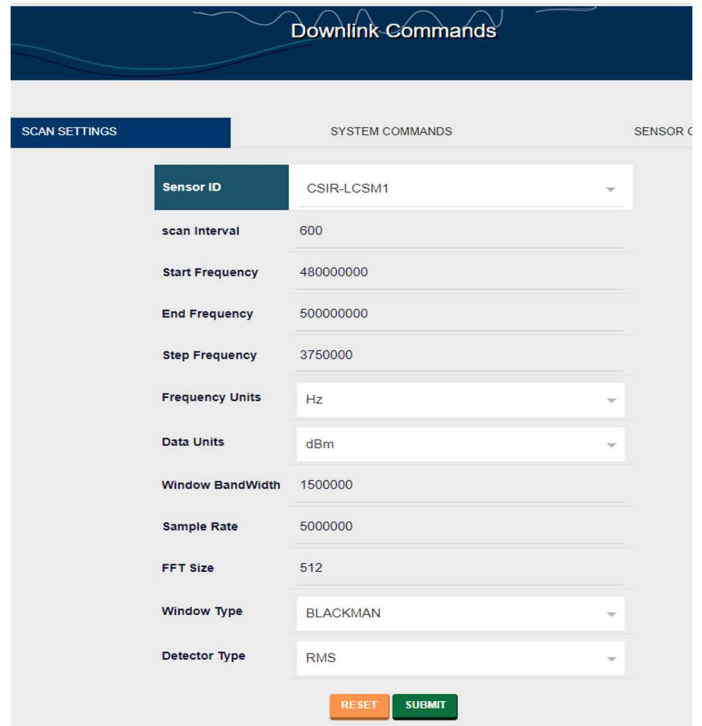

Figure 11: Downlink commands

Figure 11 above shows the Web interface screen to change the node scanning setting. Parameters adjusted are: Start frequency, Stop frequency, Sampling rate, FFT size, and bandwidth, etc.
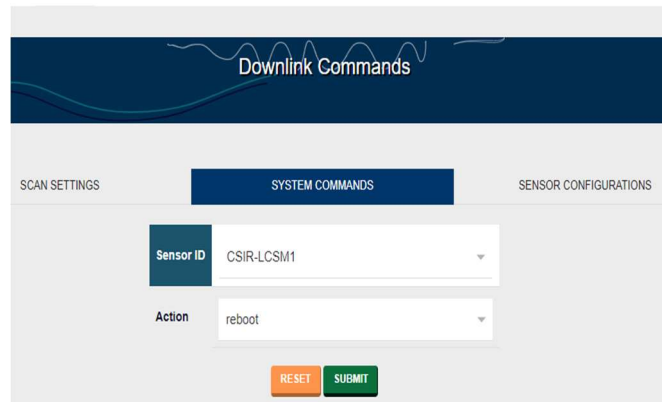

Figure 12: Downlink command: System Command

Figure 12 shows the *system command*, the *'sensor id's* dropdown enables the selection of the node we want to actuate/control, the *'action'* allows different action systems i.e *'reboot'*, *'scan now'*.

As discussed earlier the node scans the use of the spectrum and communicates the results to the SSEG via the MQTT broker. *Figure 12* shows the in graphical format the results of the spectrum scan, the time above the graph present the closest scan time the node communicated the results and the desired time we expect the node to communicate. The graph shows analog TV

and digital TV signals, the parameters are Power measuring RSSI (dBm) against frequency (MHz). Additionally, the peaks signify the spectrum usage at those frequencies and the floor shows the unused or free spectrum at those frequencies.

Figure13: Spectrum scan results graph

Figure 14: Map showing where LCSM nodes are deployed

The SSEG can show on the map the location of the LCSM nodes deployed around the country at the Universities as depicted in *figure 14*.

VI. SUMMARY AND NEXT STEPS

In this paper, we presented the progress on the development of the nationwide research platform for dynamic spectrum access (DSA) with a focus on the LCSM node that scans the spectrum and communicates remotely the results back to the backhaul system. We presented the overview of the whole system architecture and briefly explained the components. The LCSM node was assembled and put under lab tests, to test the desired functionality before shipping them to universities. The node performed well and passed all the tests. We presented the interaction between the spectrum sensing enabled GLSD web system through the MQTT message broker, additionally presented the node actuation through the downlink command from the web interface. The main goal of the infrastructure is to contribute to enhancing the decision-making of the geo-location spectrum database (GLSD), by providing it with real spectrum activity data. For future, work we are looking to use machine learning and artificial intelligence techniques to learn the spectrum usage patterns and equip the GLSD with the intelligence better provide the Dynamic Spectrum Access (DSA).

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[9] Lysko, M. Masonta, D. Johnson and H. Venter, "FSL based estimation of white space availability in UHF TV bands in Bergvliet South Africa", Southern African Telecommunicati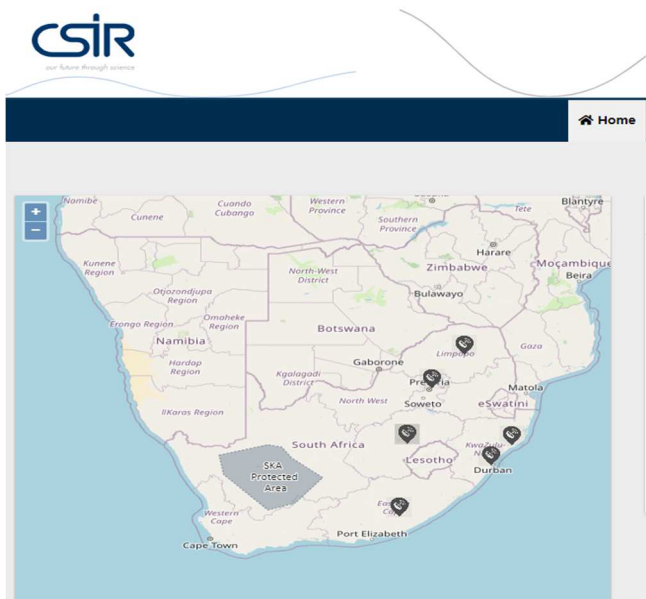ons and Network Access conference (SATNAC), Sep 2012.