RESEARCH AND DEVELOPMENT REPORT

OF

NOMADIC BASE STATION (NomadicBTS) PROTOTYPE

CARRIED OUT AT

THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING,

COLLEGE OF ENGINEERING,

COVENANT UNIVERSITY, OTA, OGUN STATE, NIGERIA

NCC GRANT RESEARCH TEAM MEMBERS

PROF. V.O. MATTHEWS, PROF. E. ADETIBA, PROF. S.N. JOHN

FINAL REPORT (Version 2022a)

FOR

NIGERIAN COMMUNICATIONS COMMISION

(NCC)

REPORT AUTHOR: PROF. E. ADETIBA

DATE: FEBRUARY 2022

1.0 Introduction

Quality degradation in cellular networks can be due to many factors such as capacity limitation, interference, unfavorable propagation condition, blocking and etc. Furthermore, non-availability of cellular services in rural communities is a major source of concern to regulators because a major segment of the citizenry that live in the rural area is isolated, which hinders effective social and economical activities. In spite of the apparent need to close this gap, operators are not motivated to extend coverage to the rural areas due to high Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) with little prospect of return on investment. Thus, the Nomadic Base Station (NomadicBTS) project was proposed to the Nigerian Communication Commission (NCC) as a cost effective solution to mitigate the capacity limitation of cellular networks in covered areas and lack of network coverage in rural communities. NCC approved our research proposal and we commenced work on the project with the arrival of the necessary components in the last week of January 2015. The implementation of the NomadicBTS prototype being presented in this report is based on the Software Defined and Cognitive Radio paradigm due to its numerous advantages over the hardware centric approach. The advantages in respect of Software Defined capability are *flexibility*, *compactness*, *scalability*, *low cost of implementation*, *portability*, *interoperability*, *reconfigurability* and etc. The Cognitive capability provides the ability to *sense the radio environment*, *discover spectrum white spaces* and *mitigate the well-known spectrum scarcity vis-a-vis wastage dichotomy* in wireless communication networks. This document contains the final report of the research endeavor on the NomadicBTS prototype implementation.

2.0 System Architectural Design and Implementation

Fig. 1 shows the architecture of the NomadicBTS system, which comprises of two major sub-modules, namely: (i) Software Defined Radio (SDR) hardware at the front end and (ii) SDR software at the back end running on a Personal Computer (PC).

2.1 NomadicBTS Hardware Front-end

There are two paths in the sub-module involved in processing of Radio Frequency (RF) signals - the receiver path and transmitter path, as shown in Fig. 1.0. In the receiver path, the received RF signal is sent via a duplexer to the Low Noise Amplifier (LNA). This signal is down-converted from RF to an Intermediate Frequency (IF) signal and the resulting signal is digitized by the Analog-to-Digital Converter (ADC). The digital signal is then forwarded to the Field Programmable Gate Array (FPGA) where it is subjected to decoding, timing, up/down sampling, data rate conversion and different access schemes such as Time Division Multiple Access (TDMA) among other processes. In the transmitter path, the digital signals are converted by the Digital-to-Analogue Converter (DAC) to analog waveforms. The analog signals are then up-converted to RF, power-amplified and forwarded to the transmitter antenna via the duplexer (Adetiba et al., 2018). The Ettus USRP-B200 was used in this work to actualize the hardware sub-module due to certain admirable properties it possesses as presented in Table 1.0 (Ettus, 2008). USRP B200 hardware covers RF frequencies for both GSM 900 and GSM 1800. The spectrum assignments in Nigeria for these two bands are shown in Figs. 2.0 and 3.0.

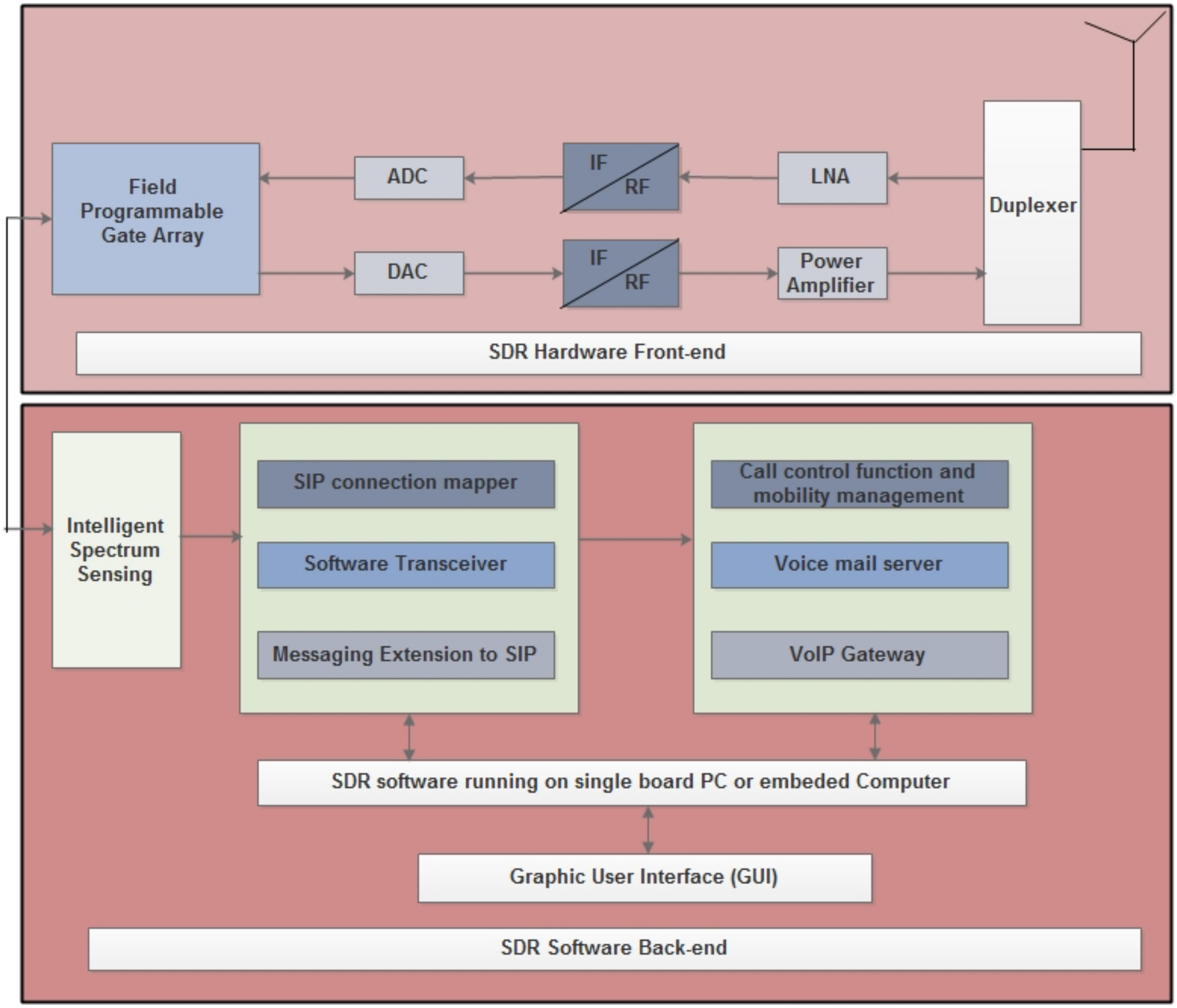


Figure 1.0: NomadicBTS Architecture

Table 1.0: Parameters of USRP B200

S/N	Description	Values
1	Radio Spectrum	0.05 – 6GHz
2	Bandwidth	50MHz
3	Duplex	Full
4	Sampling Rate (ADC/DAC)	61.44MS/s
5	Resolution (ADC/DAC)	12bits
6	DC Input	6V
7	FPGA	Spartan6 XC6SLX75
8	Interface (Speed)	USB 3.0 (4.8Gb/s)

Figure 2.0: Spectrum Allocation for 900MHz (www.ncc.gov.ng)

OPERATOR	NTEL	GLOBACOM	MTN	AIRTEL	9MOBILE
Tx	1805-1820	1820-1835	1835-1850	1850-1865	1865-1880
Rx	1710-1725	1725-1740	1740-1755	1755-1770	1770-1785
STATES					
LAGOS	NTEL	GLOBACOM	MTN	AIRTEL	9MOBILE
OGUN					
ONDO					
OSUN					
EKITI					
OYO					
KWARA					
EDO					
DELTA					
RIVERS					
BAYELSA					
AKWA IBOM					
CROSS RIVER					
EBONYI					
ABIA					
IMO					
ANAMBRA					
ENUGU					
BENUE					
KOGI					
NIGER					
ABUJA					
NASSARAWA					
TARABA					
PLATEAU					
BAUCHI					
GOMBE					
ADAMAWA					
BORNO					
YOBE					
JIGAWA					
KANO					
KADUNA					
KATSINA					
ZAMFARA					
KEBBI					
SOKOTO					

Figure 3.0: Spectrum Allocation for 1800MHz (www.ncc.gov.ng)

The software component that relates directly with the USRP-B200 device is the U*niversal Software Radio* Peripheral (USRP) *hardware driver* usually represented with the acronym – UHD. UHD enables researchers to design and develop software radios on Windows, Linux, or MacOS platforms. Various software frameworks or development environment, such as GNU Radio, MATLAB/Simulink and LabVIEW use the UHD driver to access the USRP device and it supports all USRP devices without explicit abstraction to the application.

2.2 NomadicBTS Software Back-end

It comprises of two sub-components: the Soft Base Station Subsystem (SoftBSS) and Voice over Internet Protocol Private Automatic Branch Exchange (VoIP PABX) software that runs on a host Personal Computer (PC) with an Operating System (OS). The SoftBSS interconnects the VoIP

PABX and the SDR front-end hardware. It acts as a software implementation of a transceiver and performs functions including modulation and demodulation using Gaussian Minimum Shift Keying (GMSK), clock synchronization, frequency tuning as well as transmit and receive bursts transmission. OpenBTS, an open source software, which emulates the complete stack of GSM was adopted to realize the stated functions of the SoftBSS. Furthermore, in order to establish Session Initiation Protocol (SIP) connections for processing by the VoIP PABX, SoftBSS implements the mapping functions of SIP. For instance, embedded on the Subscriber Identity Module (SIM) card of an end-user Mobile Station (MS) is the International Mobile Subscriber Identity (IMSI), which is regarded as an SIP client by the VoIP PABX. The location of the MS is mapped to the SIP registration, call connection is mapped to SIP transactions, and Short Message Service (SMS) function is achieved through instant messaging extension to SIP using SMQueue. The VoIP PABX was implemented in this work with Asterisk, which is an open source PABX. Also, among the sub-components of the Software back-end is a Graphic User Interface (GUI) as shown in Fig. 1. It enables the technical administrator to configure the NomadicBTS in order to satisfy users' requirements. The implementation of the GUI module is currently ongoing in our Laboratory.

Intelligent Spectrum Sensing block interfaces between the hardware front-end and the software back-end as shown in Fig. 1. This injects spectrum sensing, which is a Cognitive Radio (CR) capability into the NomadicBTS prototype to realize Dynamic (opportunistic) Spectrum Access (DSA). In order to achieve DSA for mobile communications ranging from 2G to 4G standards, a model was built based on Automatic Modulation Classification (AMC). In practice, activating the AMC model in the NomadicBTS prototype could help to distinguish between occupied and available states of any sensed spectrum band. If any modulation scheme associated with any of the operators is detected within their designated band, it indicates the occupied states of the spectrum band. Otherwise, if only noise is detected, it indicates the available (free) state of the spectrum band for secondary users to dynamically (opportunistically) use for communication.

The NomadicBTS prototype, which comprises of the physical interconnection of USRP-B200 module with a Laptop functioning as the host PC is shown in Fig. 4. The host PC runs the SoftBSS, VoIP PBX and AMC model and typically comprises of Intel Core i5-3210M CPU @ 2.50GHz speed with 8.00GB RAM.

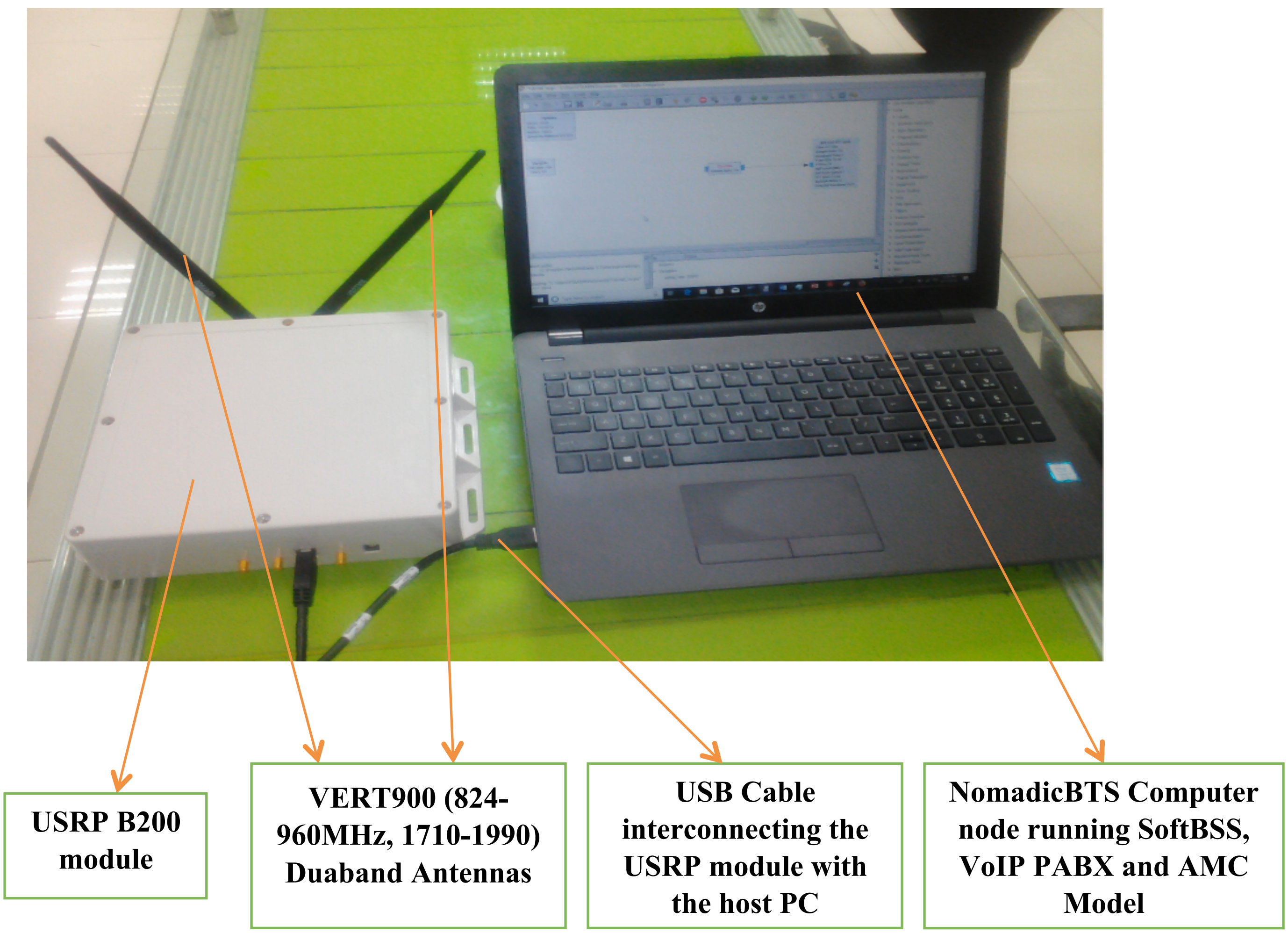


Figure 4.0: NomadicBTS Prototype Showing Interconnection of USRP-B200 with the host PC

3.0 Experiments and Results

In this section, the laboratory experiments carried out to test the functionality of the developed NomadicBTS prototype as well as the results are reported.

3.1 USRP B200 and the UHD Driver

After completing the installation of UHD on the development machine, which runs dual operating systems (Windows and Ubuntu Linux Operating Systems), we connected the USRP B200 device to the host PC and tested the functionality of the hardware device. The results obtained for all the vital tests are reported in the following subsections. These tests were run to establish the suitability of the device for the NomadicBTS project.

3.1.1 Locating the Device**:** This was achieved by opening the command prompt and typing the appropriate command. This command should normally locate the USRP B200 device and output various parameters. The output generated by using the command is shown in Fig. 5, which indicates that the device type is b200, the name field is blank, the serial number of the device is F5FF55 and the product is B200. In order to obtain detailed information on the USRP B200, another advanced command was invoked. The advanced command and the output generated are shown in Fig. 6.

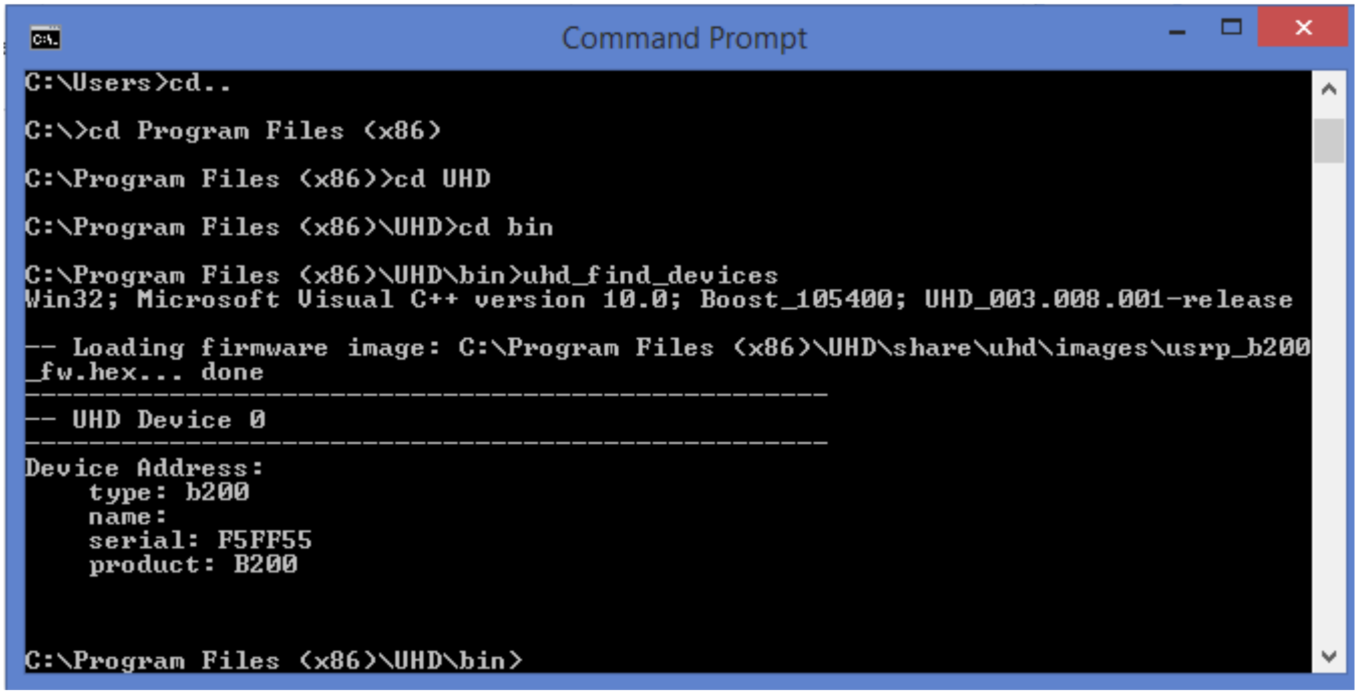


Figure 5.0: The Output Generated by Using Device Location Command

The report shown in Fig. 6 is an indication that both the UHD and the USRP B200 module can effectively communicate with the host PC.

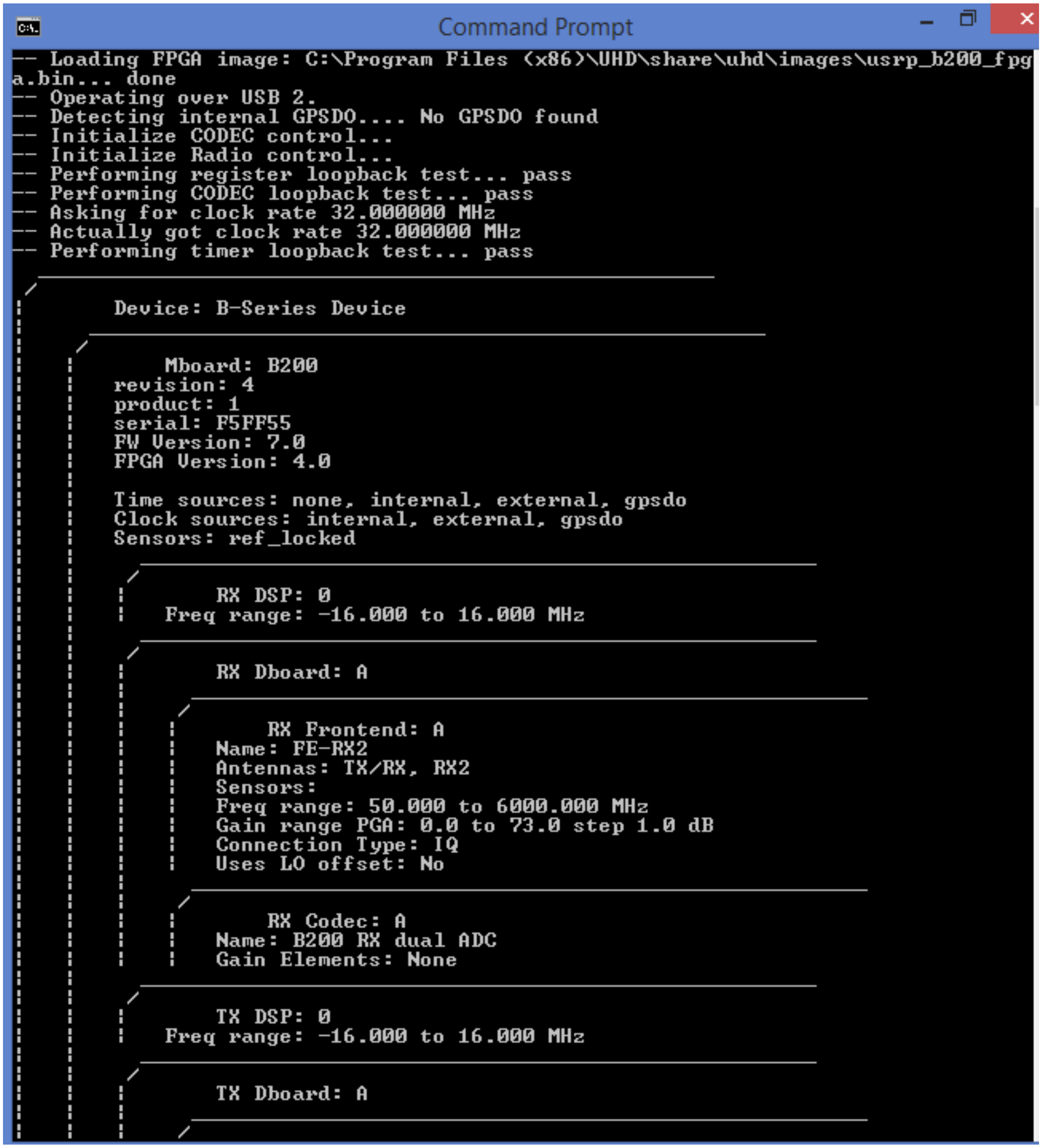


Figure 6.0: Detailed Information on the Default Configurations of the USRP B200 Device

***3.1.2 Latency Test*:** Latency test receives a packet at time *t*, and tries to send a packet at time $t + rtt$ where rtt is the round trip sample time from device to host and back to the device. The result generated by the USRP B200 device when we ran latency test on it is shown in Fig. 7.

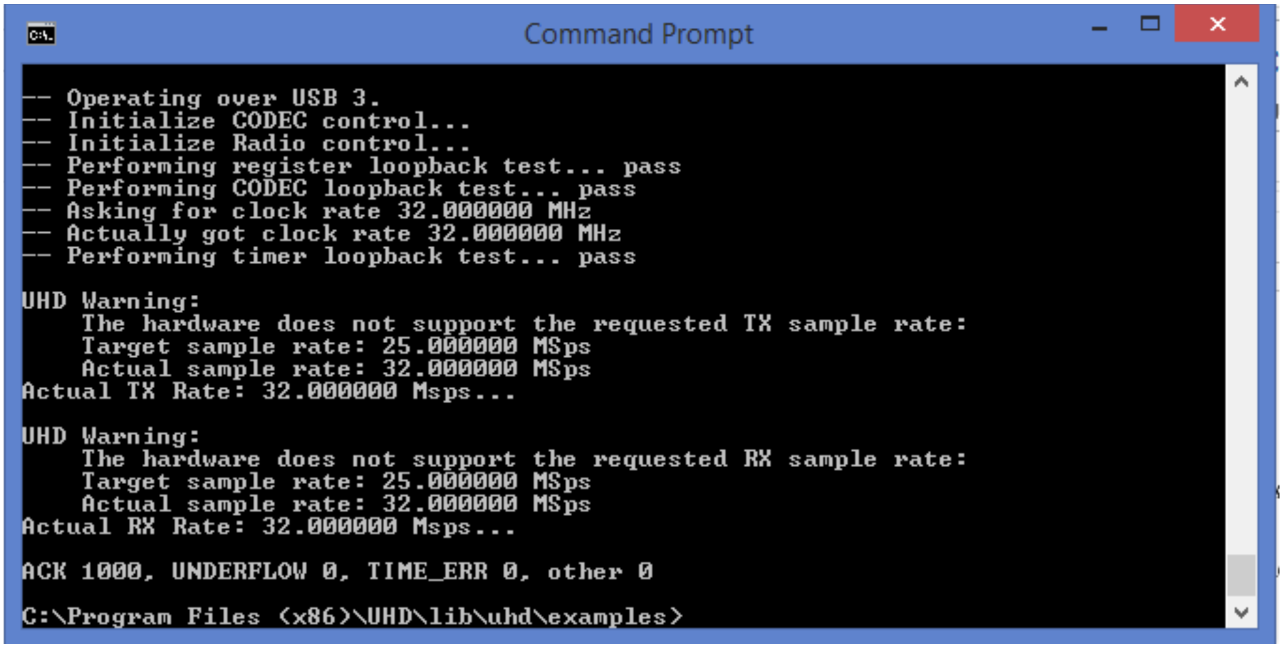


Figure 7.0: Report of the Latency Test on the USRP B200 Device

As shown in Fig. 7, all the packets sent were acknowledged (ACK = 1000) and the underflows as well as the errors were both equal to zero. These parameters are indications of good interface latency.

***3.1.3 Coercion Test*:** This is aimed at testing the USRP B200 daugtherboard(s) to ensure that they can successfully tune to all frequencies and gains in their advertised ranges. The reports of carrying out this test on the device for both transmitter and receiver are shown in Fig. 8a-d. These outputs indicate that both the *tx* and *rx* sections of the device can operate within the frequency range of 50MHz to 6GHz advertised for the device. Other vital information are shown in the Figures. Based on the outcome of this test, we can infer that the device is suitable for both GSM900 and GSM1800 operating at 900MHz and 1.8GHz respectively.

(a) (b) (c) (d)

Figure 8.0: Reports of the Coercion Test on the USRP B200 Device

3.1.4 Benchmark Test: This is aimed at testing throughput capability of the host PC with the USRP B200 device. The report obtained from this test usually comprises of the number of sent frames, overflows, dropped frames, received frames, sequence errors and underflows detected. Both the *tx* and *rx* segments of the module were tested and the report obtained are shown in Fig. 9. The report shows that transmit and receive components of the device are working optimally.

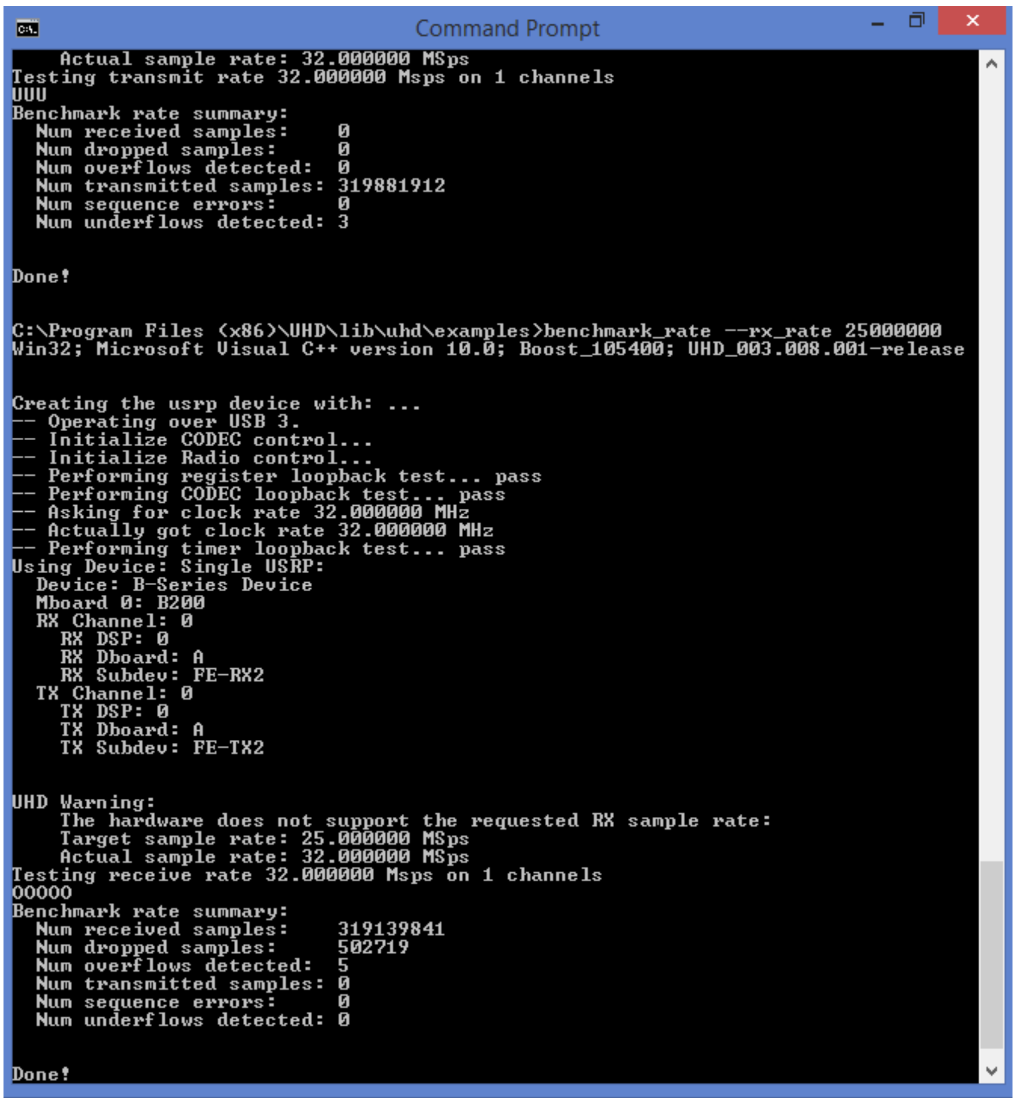


Figure 9.0: Reports of the Benchmark Test on the USRP B200 Device

3.2 Intelligent Spectrum Sensing

To develop the intelligent spectrum sensing block using Automatic Modulation Classification (AMC) model, we acquired over-the-air RF datasets for ***Amplitude Modulation (AM)***, ***Frequency Modulation (FM)*** and Gaussian Minimum Shift Keying (GMSK) modulation datasets from MTN (***GMSK_MTN***), Airtel (***GMSK_Airtel***), Globacom (***GMSK_Glo***), 9Mobile (***GMSK_9Mobile***) and ***Noise*** (for no modulation). Thus, the AMC model contains seven different output classes. The flowchart in Fig. 10 illustrates the implementation blocks of the AMC model while Figs. 11 and 12 show the locations where the datasets were acquired for MTN and Globacom at Cananaaland, Ota, Ogun State, Nigeria.

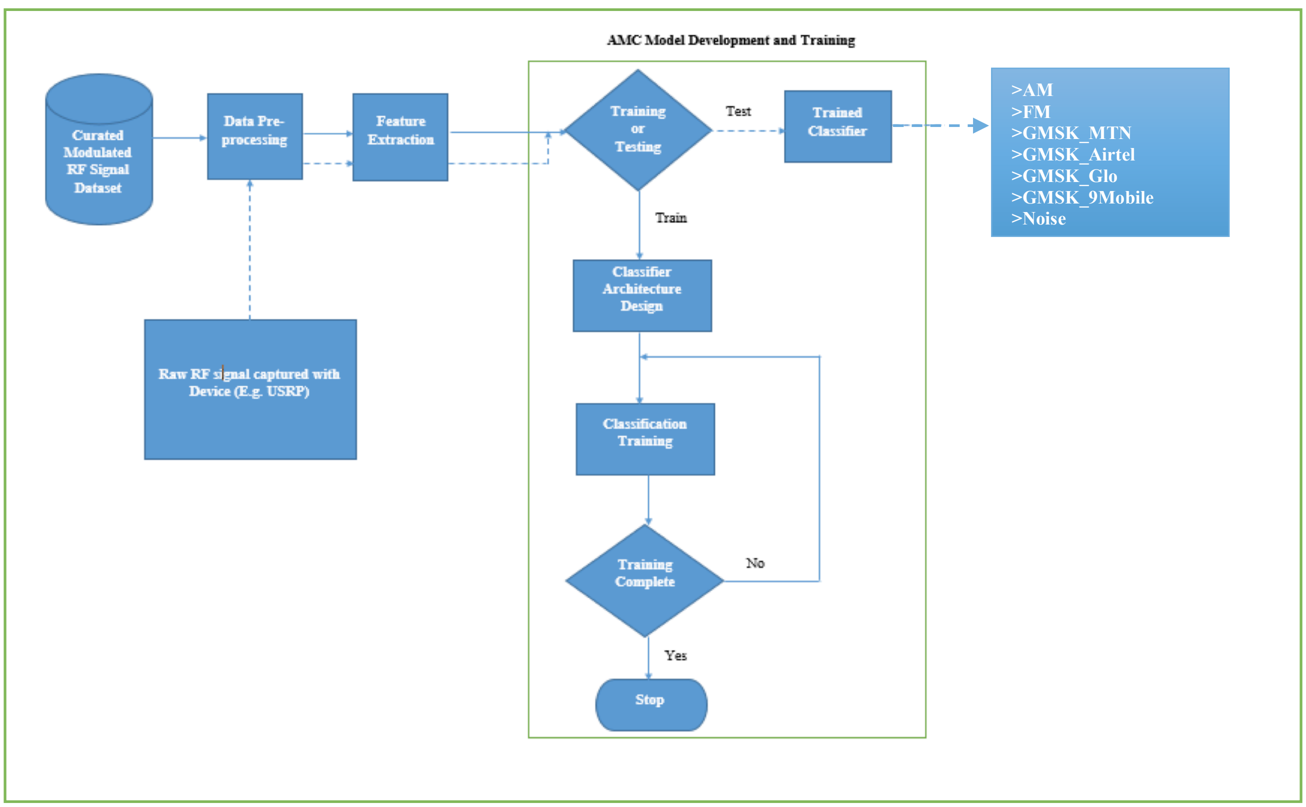


Figure 10.0: Flowchart for Intelligent Spectrum Sensing Implementation with AMC Model

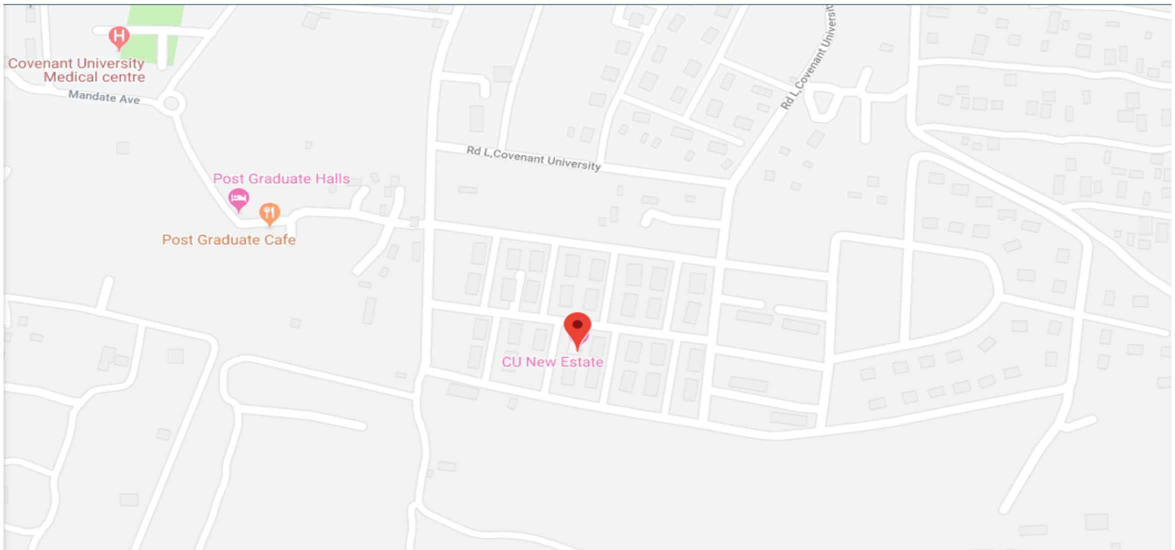


Figure 11.0: Location of the MTN Base Station where GMSK RF Dataset was Acquired (Latitude 6.6658^{0}N, Longitude 3.1588^{0}E).

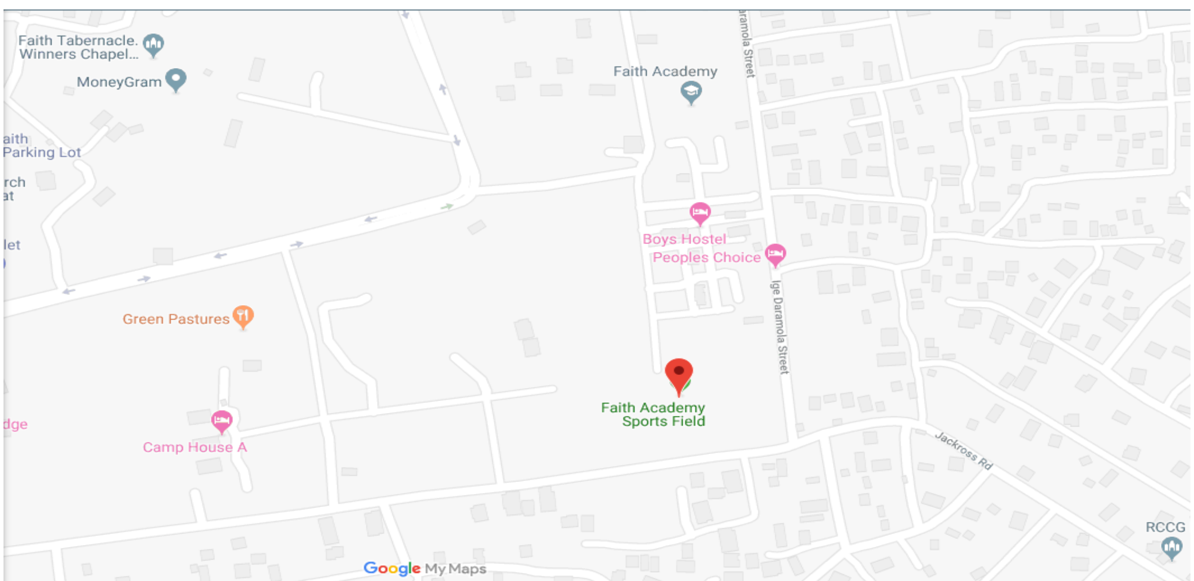


Figure 12.0: Location of the Globacom Base Station where GMSK RF dataset was Acquired (Latitude 6.6732^{0}N, Longitude 3.1724^{0}E).

We utilized GNU Radio open source software installed on the host PC and the USRP B200 module to acquire the real-time RF datasets for building the AMC model. GNU Radio software provides a set of signal processing blocks that are written in C++, with scripting support implemented using Python. GRC (GNU Radio Companion) is an Integrated Development Environment (IDE) that provides GUI interface to GNU Radio. The GRC flowgraph for data acquisition is presented in Fig. 13.

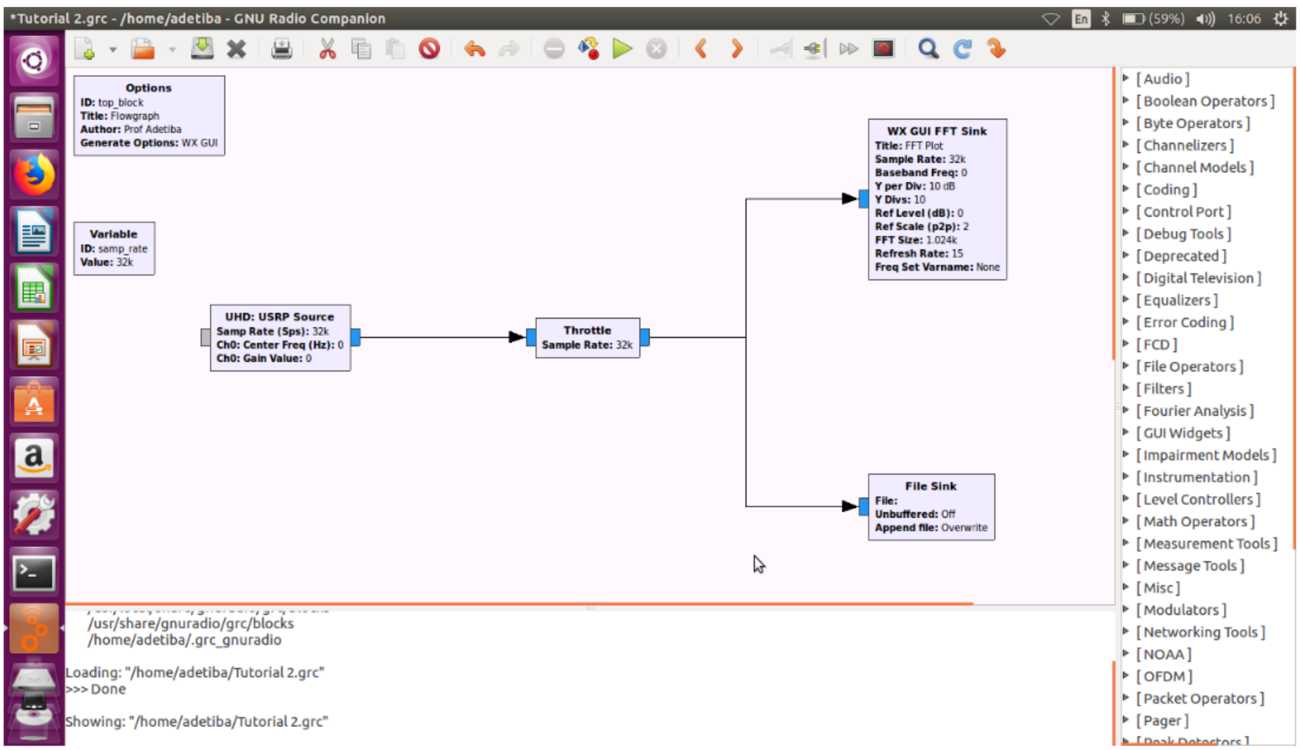
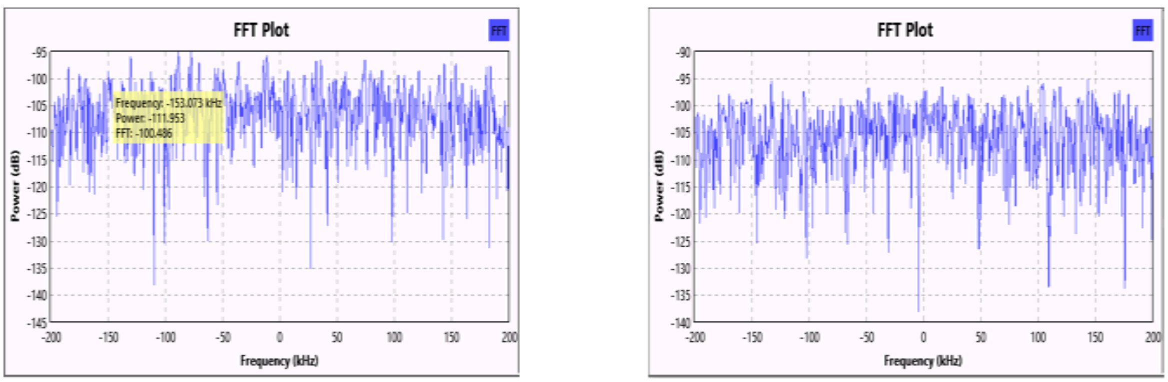


Figure 13.0: Flowgraph for Modulated Signal Capturing

First Order Statistics (FOS) was engaged to extract discriminatory features from each of the samples in the respective AMC classes (i.e. AM, FM, GMSK_MTN, GMSK_Airtel, GMSK_Glo, GMSK_9Mobile and Noise). The eight FOS features used are the ***mean***, ***variance***, ***standard deviation***, ***skewness***, ***kurtosis***, ***root mean square***, ***entropy*** and ***median***. The extracted features were further used to experimentally train and test Multi-Layer Perceptron Artificial

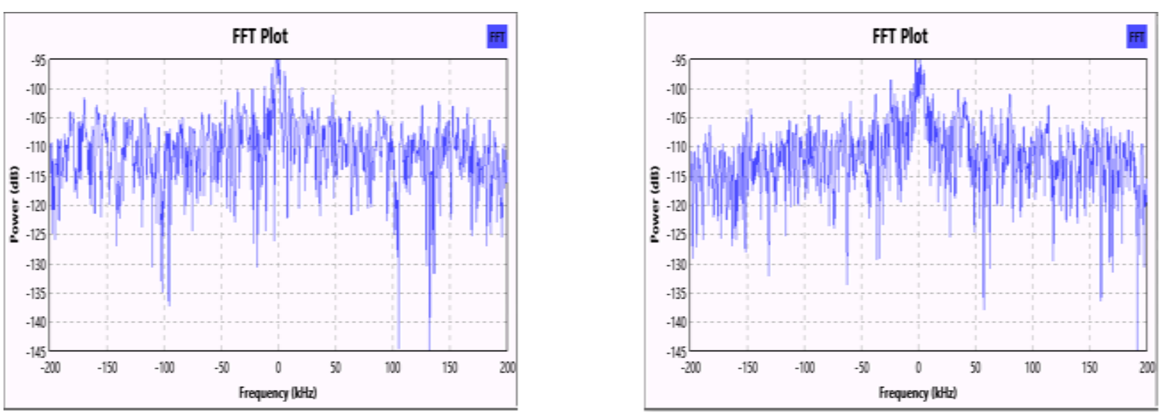
Neural Networks (MLP-ANN) in order to realize the classification component of the AMC model. FOS implementation and the MLP-ANN training and testing were carried out in MATLAB R2017a IDE.

Figures 14 – 17 show the various spectrum plots for some of the acquired raw RF signal samples. These spectrum plots were generated using FFT sink in GRC environment and visual inspection clearly show that the signals in each of the seven classes have low intra-class and high inter-class variance.



Sample 1 Sample 2

Figure 14.0: Spectrum Plots for AM signals



Sample 1 Sample 2

Figure 15.0: Spectrum Plots for FM signals

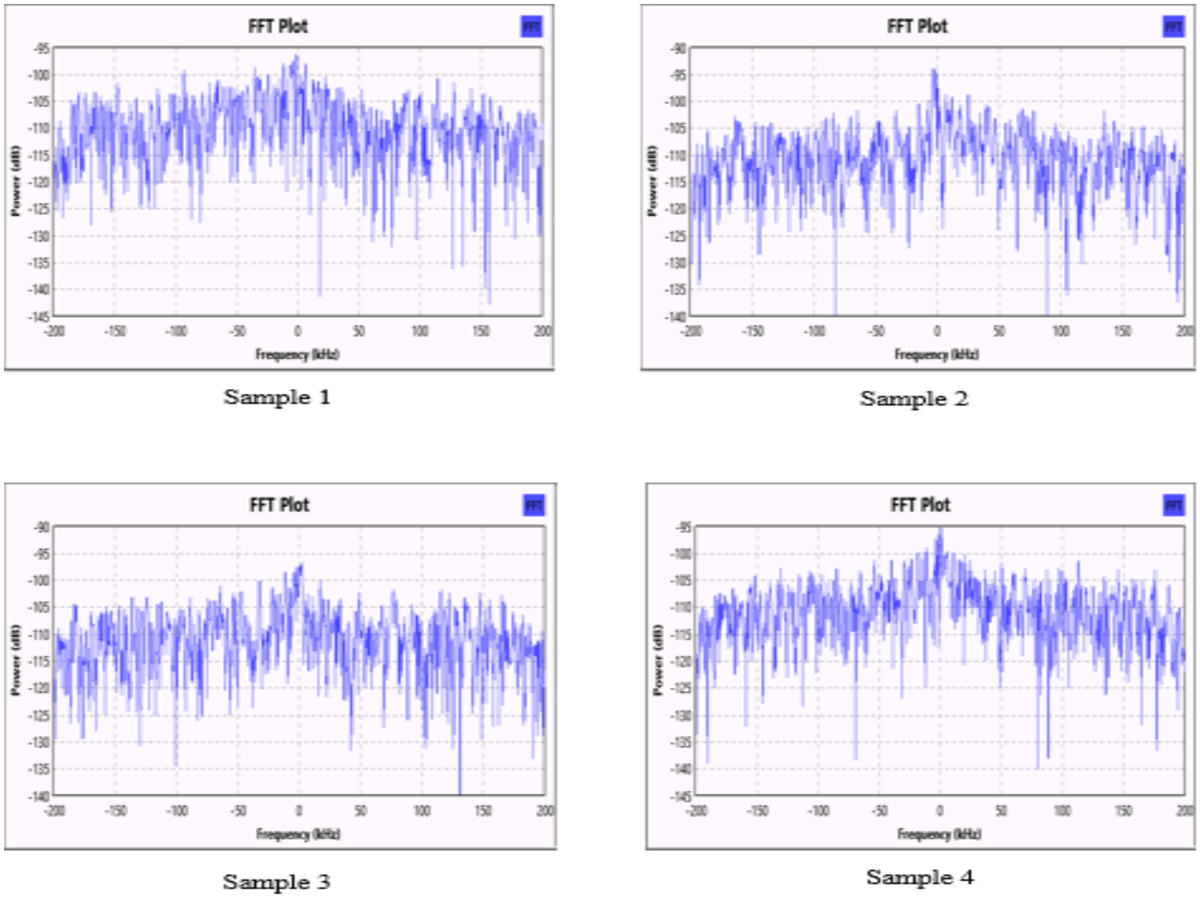


Figure 16.0: Spectrum Plots for GMSK_Airtel (Sample 1), GMSK_9mobile (Sample 2), GMSK_Glo (Sample 3) and GMSK_MTN (Sample 4) Signals respectively.

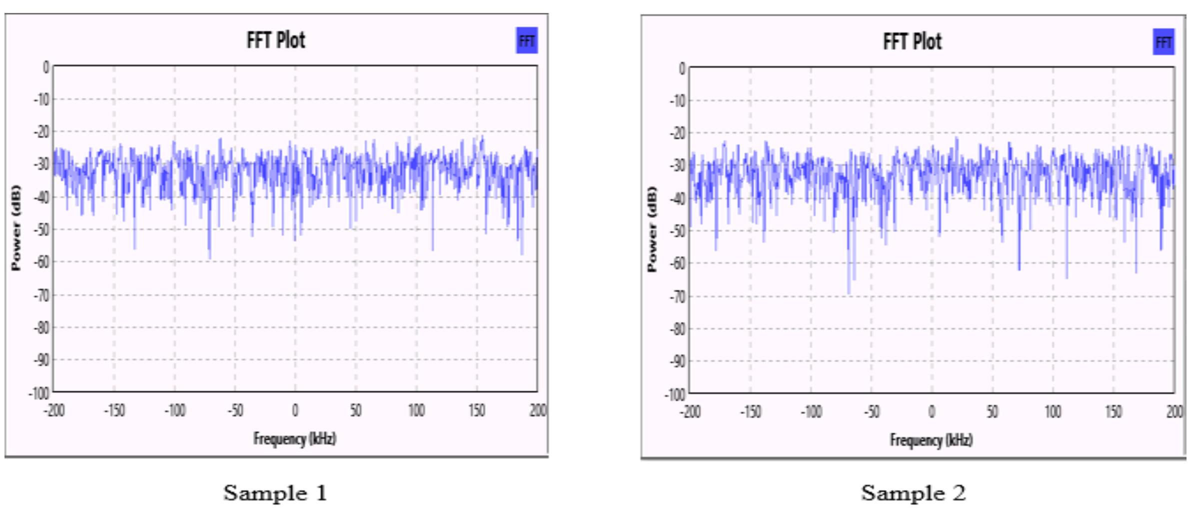


Figure 17.0: Spectrum Plots for Noise Signals

From the analysis of MLP-ANNs training results in the experiments, the minimum Mean Square Error of 0.0185 and maximum accuracy of 92.57% were achieved using the Levenberg-Marquardt (LM) backpropagation training algorithm with the MLP-ANN having ten neurons in the hidden layer. Other configurations of the best MLP-ANN in the experiments are presented in Table 2.0 and its topology is shown in Fig. 18.

Table 2: Configurations of the Best Experimentally Developed AMC Model

Number of input layer neurons	8
Number of hidden layer neurons	10
Number of output layer neurons	7
Activation function for the input layer	Purelin
Activation function for the hidden layer	Tan-sigmoid
Activation function for the output layer	Tan-sigmoid
Mean Square Error (MSE)	0.0185
Accuracy	92.57%
Learning algorithm	Levenberg-Marquardt (LM)

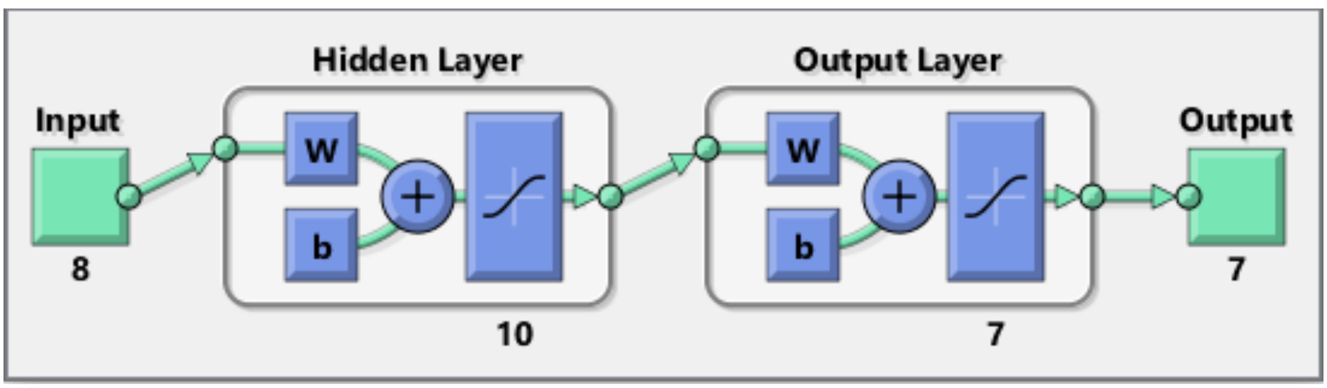


Figure 18.0: Topology of the Best Experimentally Developed AMC Model.

The results hitherto presented for intelligent spectrum sensing in NomadicBTS using AMC model, demonstrates the possibility of optimum classification of signals with similar modulation scheme but operating at different frequency bands. This provides opportunities for detecting operators with spectrum hole (white space) in a particular geographical location or at a given time, which other operators could opportunistically loan for capacity enhancement as secondary users. This could help to eliminate the need for a priori configuration of the NomadicBTS before field deployment but allows dynamic spectrum access with no interference with the primary users, thereby incorporating Cognitive Radio capability.

3.3 Testbed for the NomadicBTS Prototype

In a GSM network, two separate frequencies are used so that the mobile station and the base station can communicate simultaneously in both directions. The Absolute Radio Frequency Channel Number (ARFCN) selected is what determines the pair of frequencies that is chosen for communication. Within the GSM900 spectrum, the range of ARFCN is $1 \leq n \leq 124$ with the uplink frequency computed as $890+0.2n$ while the downlink frequency is $f_{up}(n)+45$. We setup a laboratory testbed for the NomadicBTS prototype to operate at 900 MHz band using an ARFCN of 25, which falls within the NTel frequency band (Fig. 2), which is unoccupied at the location of the prototype cell. The signal strength measurement was used to determine how seamless the mobile device could connect to the NomadicBTS prototype cell. Signal strength was represented with Received Signal Strength Indicator (RSSI) measured in dBm in ***Network Signal Info Pro,*** which is a mobile app for wireless communication. Arbitrary Strength Unit (ASU)—an integer value that is proportional to RSSI was also used to present the signal strength alongside the RSSI by ***Network Signal Info Pro***. The interpretation of the ASU values is shown in Table 3.

Table 3.0: Description of Arbitrary Strength Unit Integer Values

S/N	Arbitrary Strength Unit Range	Description
1	0-1	Very very weak signal strength
2	2-3	Very weak signal strength
3	4-5	Weak signal strength
4	6-7	Normal signal strength
5	8-10	Good signal strength
6	13-31	Perfect signal strength

3.3.1 Computation of the NomadicBTS Prototype Cell Radius

The signal strength obtained at an approximate distance of 30 cm from one of the test mobile phones (on which the ***Network Signal Info Pro*** app was installed) to the prototype cell in this work is shown in Fig. 19. The signal strength is −57dBm with 28ASU. Based on the description of ASU in Table 3, this is a perfect signal strength. Other relevant descriptions of the prototype cell are shown in Figure 19.

Also, the signal strengths were measured at different locations within the vicinity of the prototype cell, which was setup at the South-Eastern end of the Electrical and Information Engineering (EIE) building within Covenant University, Ota, Nigeria (latitude 6.6718°N, longitude 3.1581°E). At the car park between the Civil Engineering and EIE buildings, the received signal strength (−101dBm, 6ASU) was found to be normal while at the reception lobby of the EIE building, the received signal strength (−103dBm, 5ASU) was found to be weak

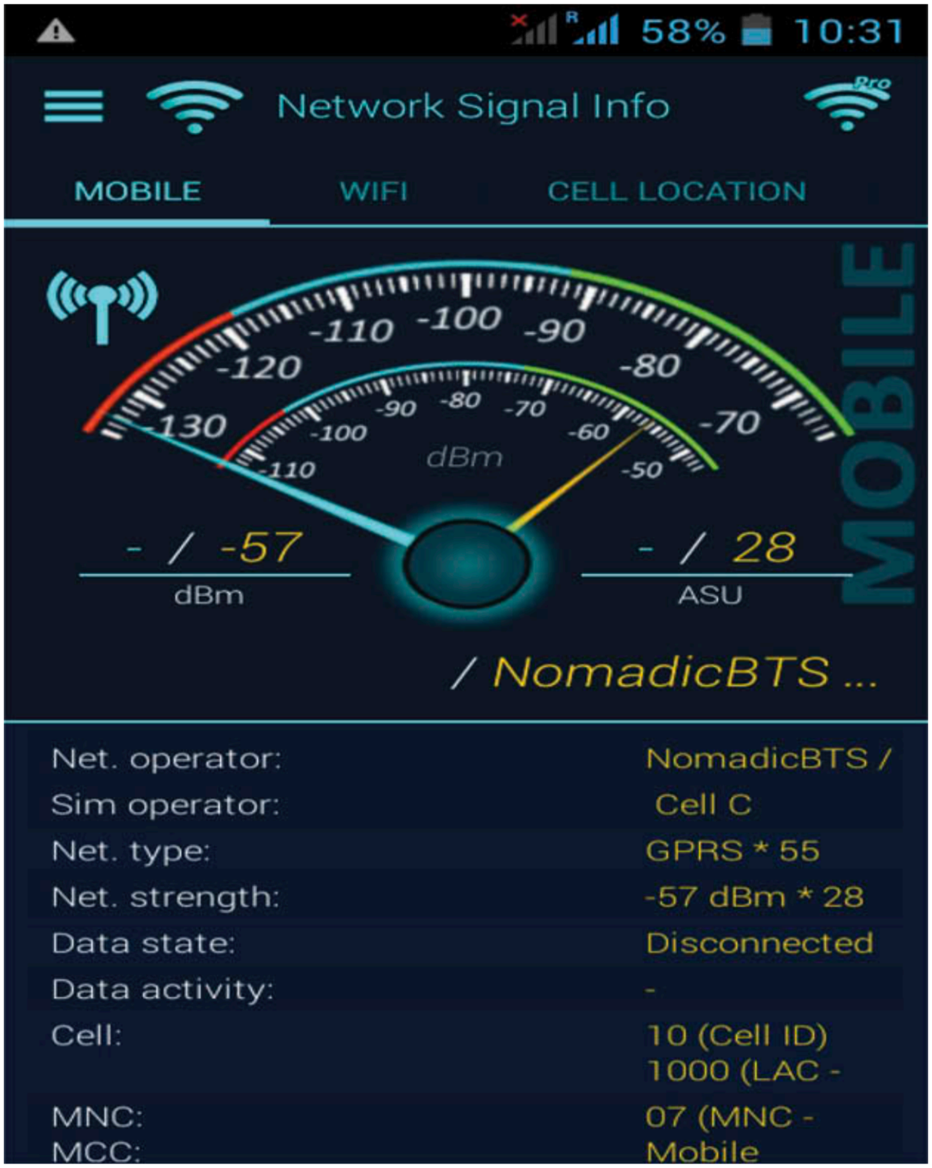


Figure 19.0: Signal Measurement on a Test Mobile Phone at Close Proximity to the NomadicBTS Prototype Cell

The radius of the prototype cell is computed using Equation 1 (Frattasi & Della, 2017).

$$R_c = r \times 10^{\left(\frac{dBm+113}{40}\right)} \tag{1}$$

where Rc is the cell radius, r is the distance from the test mobile phone to the prototype cell site, and dBm represents the measured signal strength at r. Using the signal strength at approximately 30 cm from the prototype cell, which is −57 dBm, we have:

$$R_c = r \times 10^{\left(\frac{-57+113}{40}\right)} = 753.57\text{cm}$$

Therefore, the approximate cell radius of the prototype cell is 7.54 m, which can be described as an approximate femtocell with capability for cellular communications within homes or offices.

3.3.2 Mobile Stations Registration and Communication on the Prototype Cell

As earlier established, the testbed for the NomadicBTS prototype cell has a radius of 7.54 m, which is confined within the laboratory based on authorization by NCC. This is a femtocell and consequently, there is negligible interference with active commercial traffic. We measured the excess noise and radio interference from external sources on the uplink of the prototype cell. This is because signals from the test phones will not demodulate if the uplink noise and/or interference is too high. Based on the test carried out, the environmental noise RSSI gave -78dB and since the target RSSI for handsets is -50dB, this implies that the NomadicBTS can receive 28dB more energy from the handsets than the environmental noise. As shown in Fig. 20, the two test phones used for this study are Window's NOKIA Lumia 530 and Android BLU DASH 5.0 phones. The two test phones were able to successfully register on the prototype cell whose network ID is NomadicBTS as shown in Fig. 20.

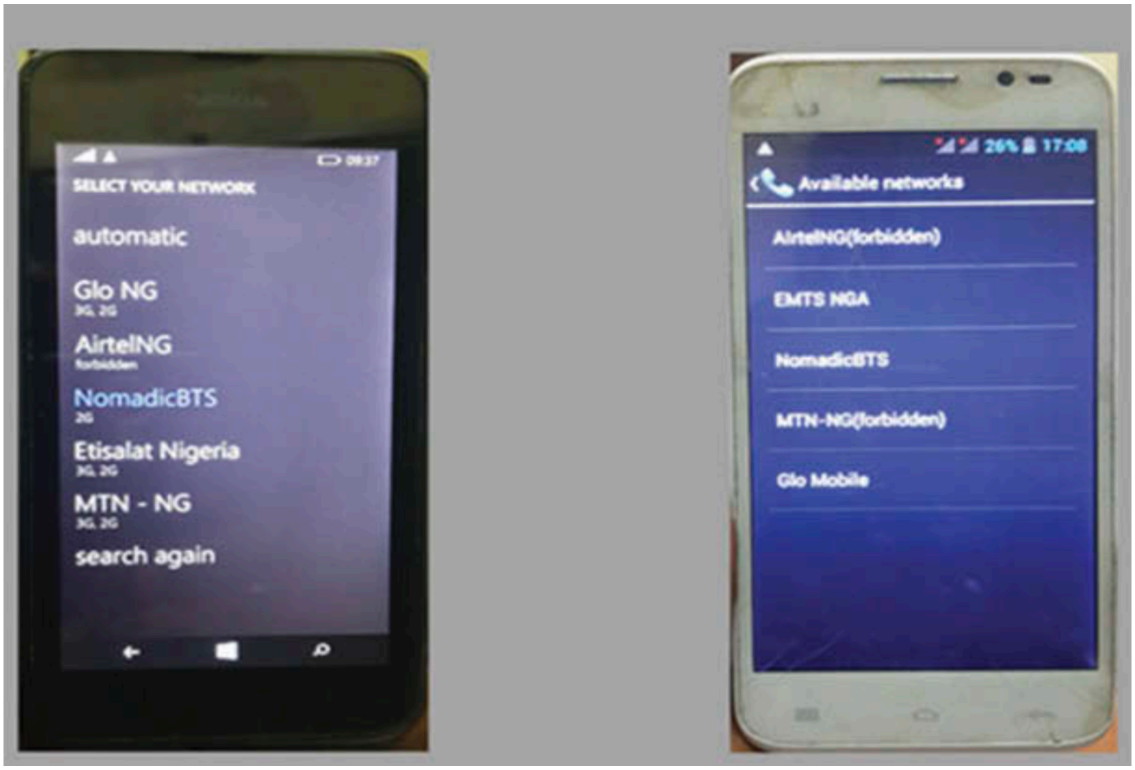


Figure 20.0: Successful Registration of Test Phones on the NomadicBTS Prototype Cell

The prototype cell was further tested by sending an SMS text with the BLU DASH as the sender with a subscriber ID of ***0000655073322311152*** and the NOKIA Lumia as the recipient with an ID of ***123456789***. These subscriber IDs were configured on the NomadicBTS prototype cell. The successfully sent and received text messages are shown in Figure 21.

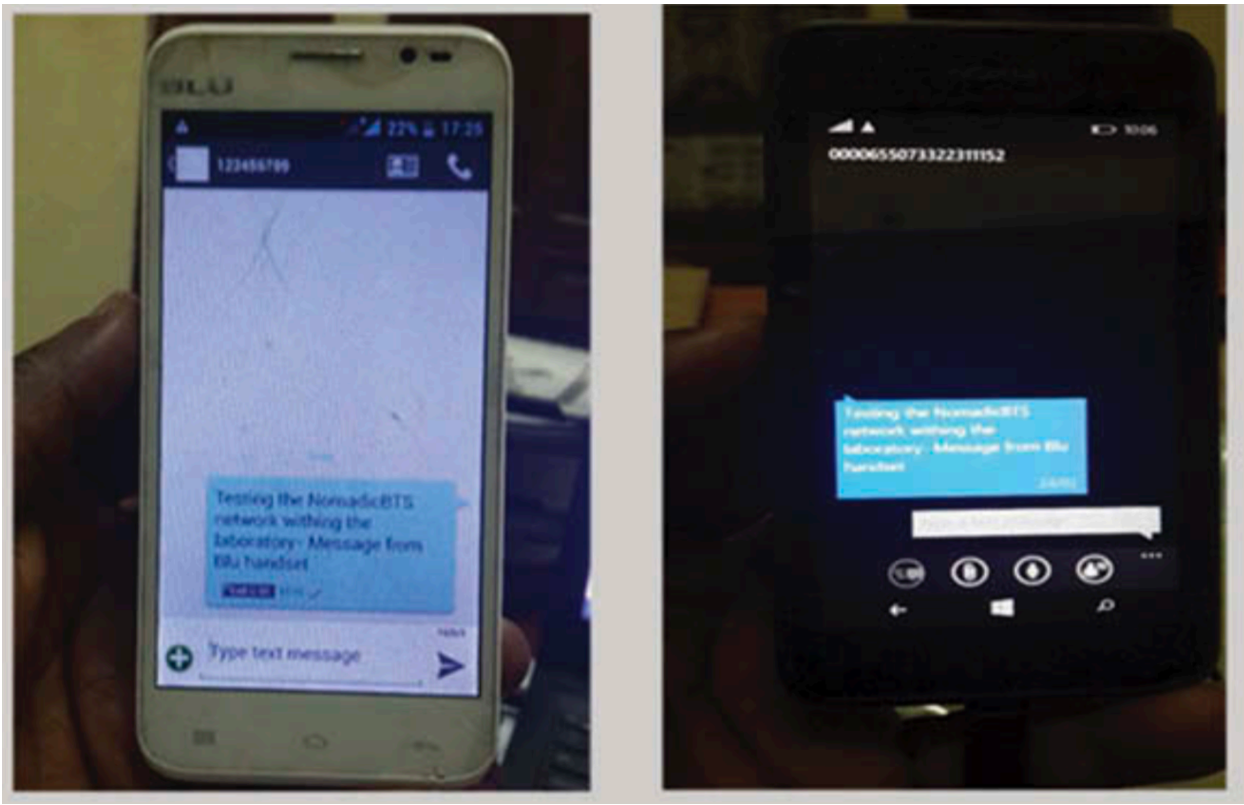


Figure 21.0: Successful SMS Communication Between the Test Phones on the NomadicBTS Prototype Cell.

Furthermore, we carried out echo test for voice communication within the coverage of the prototype cell and the cell provided a clear and intelligible echo response to the two Test Phones with no delay. The current work provides a proof of concept and real-time implementation of the simulation work reported in (Adetiba et al., 2011).

It is noteworthy that the quality of a radio link is best evaluated when the traffic channel is in use at a time instance on the network. In order to evaluate the link quality, a dial tone call was initiated for GSM1800, and the *chans* command (in OpenBTS) was executed to measure the link quality as the MS moved away from the NomadicBTS. For each time instance, an active channel was observed; the uplink Signal-to-Noise Ratio (SNR) and Received Signal Level (RXLEVEL) decreased with distance (fading), while the Transmit Power (TXPWR) of the NomadicBTS increased as shown in Table 4.0.

Table 4.0: Link Quality Measurement at GSM 1800MHz

	GSM 1800MHz		
Distance (m)	Rxlevel (dBm)	TxPower (dBm)	SNR
1	-99	24	60.9
2	-98	28	58.3
3	-107	24	49.7
4	-101	24	56.6
5	-105	26	56.5
6	-104	26	35.1
7	-100	28	48.5
8	-111	30	49

3.3.3 NomadicBTS Web Application

The NomadicBTS web application within the Software Backend of the architecture in Fig. 1 provides an interface between the admin (user) and SoftBSS/VoIP PABX components. This allows GUI based configuration of the different software services in the SoftBSS/VoIP PABX. These services are *OpenBTS*, *SMQueue*, *Asterisk*, *SIPAuthServe* and *NodeManager*. The web application architecture consists of the front-end and back-end as shown in Figure 22.

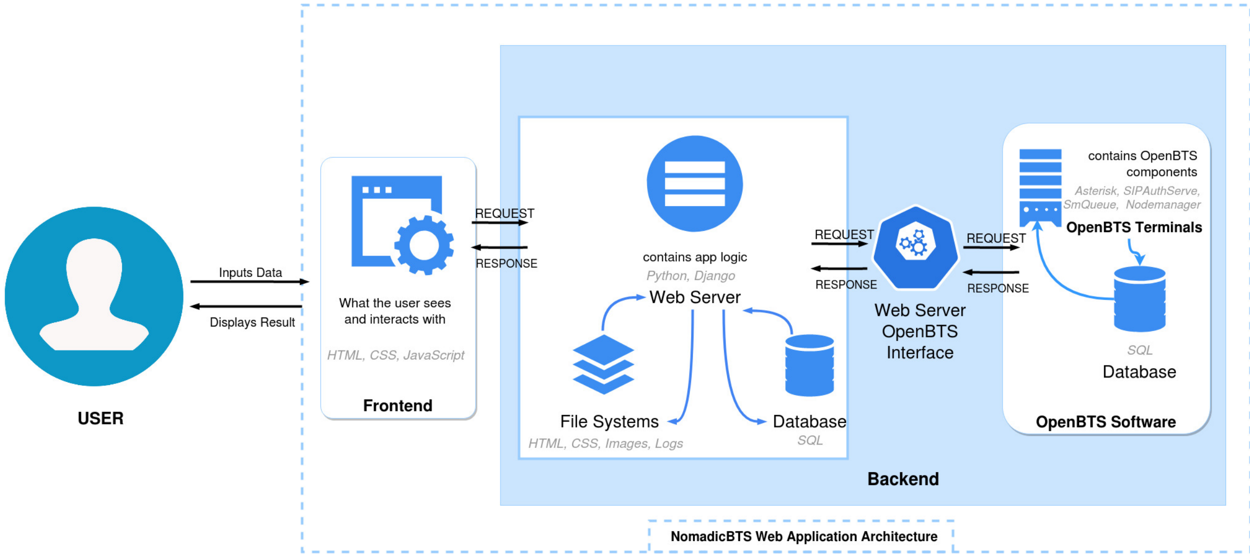
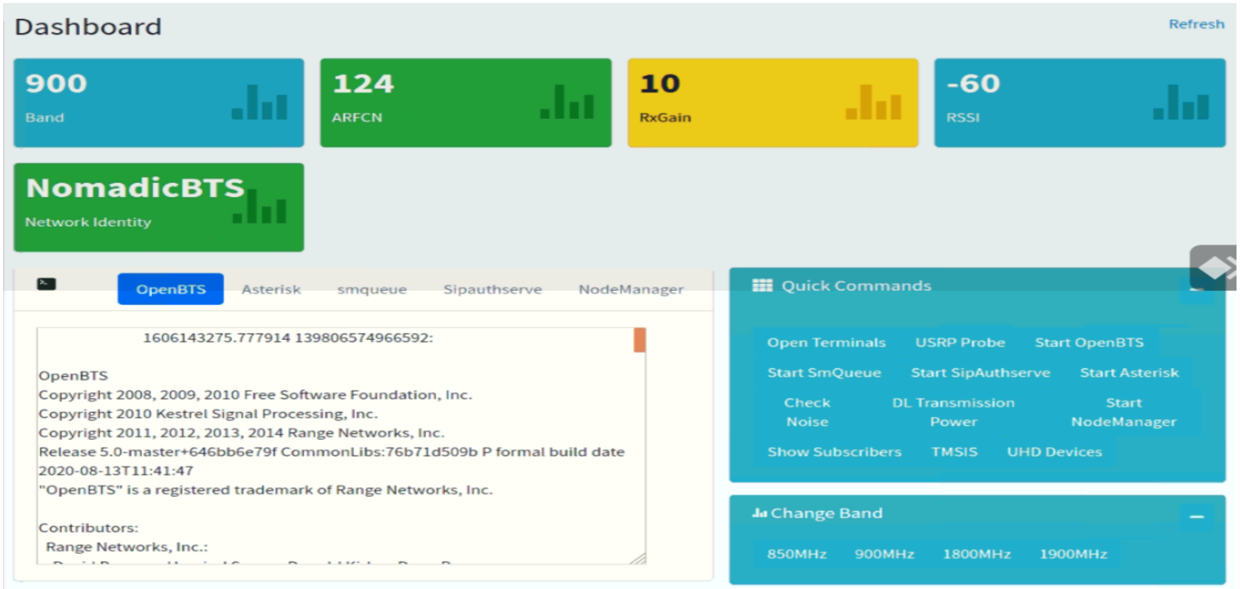
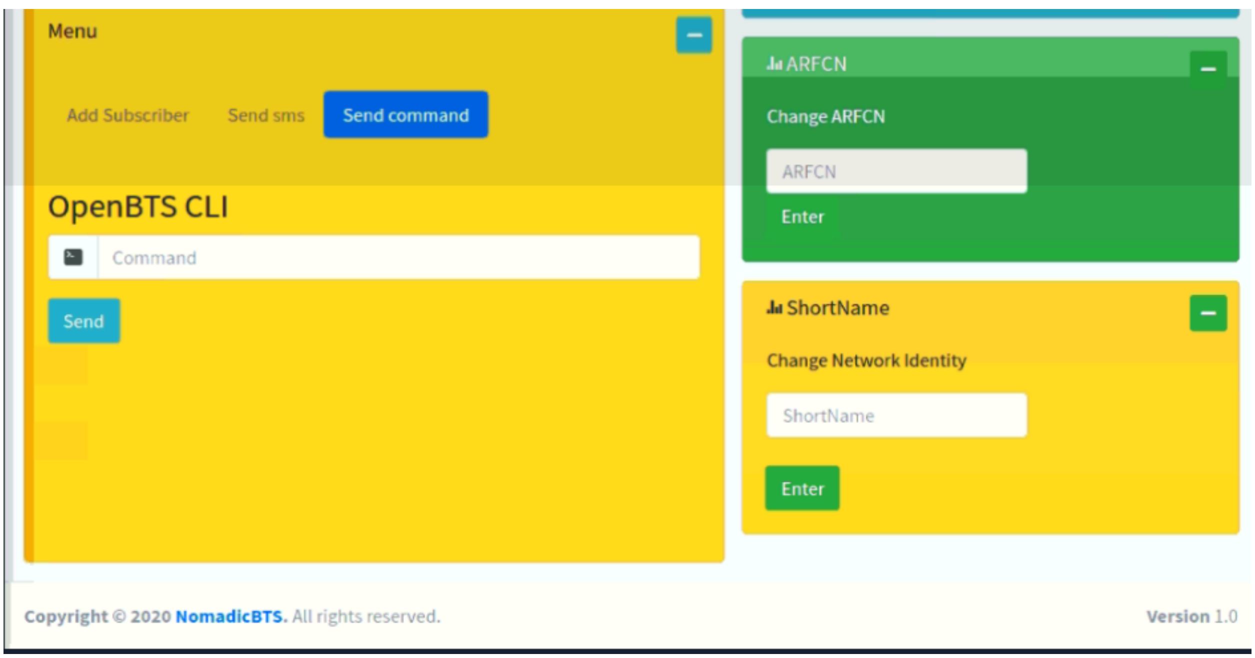


Figure 22.0 NomadicBTS Web Application Architecture.

The front-end of the app presents to the admin (user) a modern interface rendered by a web browser such as Chrome, Firefox, Edge or Safari. It was implemented with a combination of HTML, CSS and Javascript. These scripts are delivered to the web browser as responses to requests made by the user. Fig. 23 (a) and (b) show the dashboard with various collapsible mini windows on the front-end. In Fig. 23a, NomadicBTS is clearly shown as the network identity. The current configurations of the OpenBTS service such as the configured band (900MHz), ARFCN (124), RxGain (10) and RSSI (-60dBm) are shown on the topmost bar of the dashboard. The outputs of the different services are presented as separate tabs, which make it easy for the admin (user) to examine the current status of any of the services. The other mini windows (as shown in Fig 23b) contains group of menu items that the admin (user) can leverage in an easy-to-use graphical mode to execute various commands for maintaining and troubleshooting the NomadicBTS during operation.



(a)



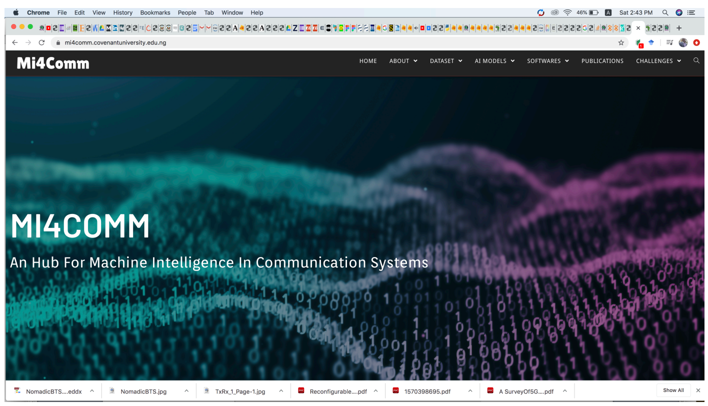
(b)

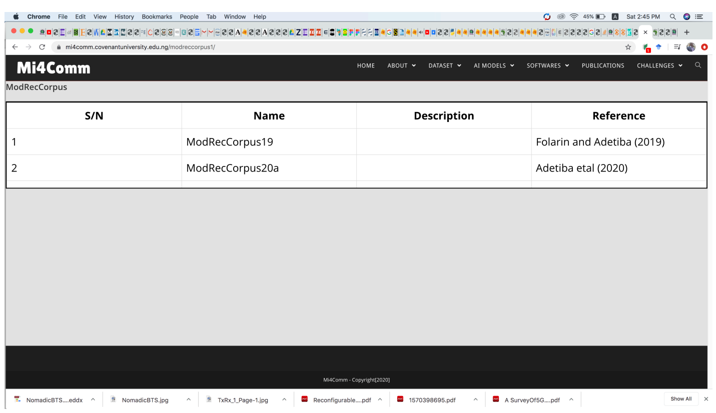
Figure 23.0 NomadicBTS GUI

The backend of the NomadicBTS Web App consists of the web server (django framework), installed services for the SoftBSS/VoIP PABX (i.e. *OpenBTS*, *Asterisk*, *SMQueue*, *SIPAuthserve* and *NodeManager*) as well as the Interface/Gateway between the services and the web server.

4.0 Research Datasets

Curated and operational datasets are vital resources that could aid further studies on the application of Artificial (Machine) Intelligence in Communication Systems. Notably, Cognitive Radio represents one of the connecting links between Communication Systems and Artificial Intelligence. Thus, an online corpus is been developed to archive the curated modulation datasets as well as the NomadicBTS prototype cell operational logs datasets (see Fig. 24). Once completed, the datasets can be accessed by researchers all over the world to develop AI based Communication System models, algorithms, testbeds and prototypes.





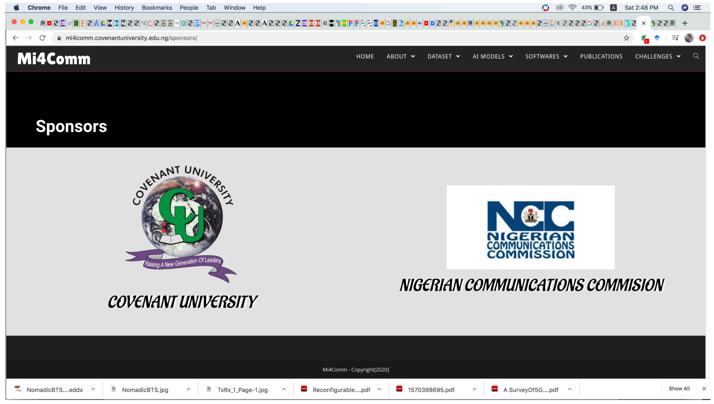


Figure 24.0: MI4Comm: An Online Hub for Machine Intelligence Datasets, Models and Algorithms

5.0 Recommended Future Works on the Project

The following are future tasks vis-à-vis features that are required for continuous improvement of the NomadicBTS project.

i) Upgrade of the NomadicBTS prototype for real-time deployment towards cost effective cellular networks for capacity enhancement in covered areas and extension of coverage to uncovered areas.

ii) Enhancement of the Software Back-end module to support full cognitive capabilities (DSA, intelligent handover, spectrum management and spectrum sharing), billing, DSA based opportunistic billing, interconnection with traditional 2G/2.5G/3G/4G, current 5G and prospective 6G networks.

iii) Production of custom SIM cards for the NomadicBTS cells.

iv) Replication of the NomadicBTS prototype in research and teaching laboratories across Nigerian Higher Education Institutions (HEIs) towards practical oriented training on Software Defined and Cognitive Radio paradigm, which is the bedrock of modern wireless communication.

v) Issuance of experimental licenses within the mobile communication spectrum bands for advanced wireless communication research in Nigerian Universities and research institutions.

vi) Recruitment of Research Assistants (RAs) comprising of Masters and Ph.D students as well as Post-Doctoral Fellows (PDFs) to substantially extend the work and ultimately for transfer of the acquired knowledge from the implementation of the prototype.

6.0 Publications from the Research Work

The following are scholarly outputs so far produced in the course of the NomadicBTS project.

i) Adetiba, E., Matthews, V.O., Daramola, S.A., Samuel, I.A., Awelewa, A.A. and Eleanya, M.E.U., 2011. **Nomadic Base Station (NBS): A Software Defined Radio (SDR) based architecture for capacity enhancement in mobile communications networks**. *International Journal of Engineering & Technology IJET-IJENS*, 11(1), pp.191-195.

ii) Adetiba, E., Matthews, V.O., John, S.N., Popoola, S.I. and Abayomi, A., 2018. **NomadicBTS: Evolving cellular communication networks with software-defined radio architecture and open-source technologies**. *Cogent Engineering*, *5*(1), p.1507465.

iii) Folarin. J. Olaloye, Emmanuel Adetiba, 2019. **Dynamic Spectrum Sensing with Automatic Modulation Classification for a Cognitive Radio Enabled NomadicBTS,** 3rd International Conference on Engineering for Sustainable World (ICESW2019), July 3rd – 8th 2019.

iv) Folarin J. Olaloye**, Cognitive Radio Enabled Nomadic Base Transceiver Station towards Opportunistic Spectrum Sensing in Mobile Communication Networks**, Masters Dissertation, Covenant University, Ota, Nigeria, May 2019. Supervised by Emmanuel Adetiba, Ph.D, R.Engr. (COREN).

v) Sunday Ajala, Emmanuel Adetiba et al., 2021 **Experimentations on the Transmit Power Of a Universal Software Radio Peripheral Using GNU Radio Framework,** In IOP Conference Series: Earth and Environmental Science (Vol. 655, No. 1, p. 012006). IOP Publishing.

vi) Sunday Ajala, Emmanuel Adetiba *et al.,* 2021. **Automatic Modulation Recognition Using Minimum-Phase Reconstruction Coefficients and Feed-Forward Neural Network** (To be Published by the Journal of Computing Engineering and Science).

vii) Jamiu R. Olasina, Emmanuel Adetiba et al. 2022. **Automatic Modulation Recognition Models Based on Transfer Learning and Simulated Radio Signals in AWGN Channels,** Innovations in Bio-Inspired Computing and Applications, Springer.

viii) Emmanuel Adetiba et al., 2022. **Compact Automatic Modulation Recognition Model with Over-the-Air Radio Frequency Signals, First Order Statistical Features and Shallow Machine Learning** (Under Review by Bulletin of Electrical Engineering and Informatics).

ix) Emmanuel Adetiba et al., **NomadicBTS-2: A Network-in-a-Box with Software-Defined Radio Frameworks and Web Based Configuration App for**

Multiband Cellular Communication (To be submitted to Journal of Engineering, Hindawi)

7.0 Conclusion

The fund provided by NCC has helped thus far towards the realization of the NomadicBTS project's objectives. This is highly commendable and appreciated. We have been able to prototype and test a single NomadicBTS based cellular network within our laboratory at Covenant University. Further plans on the project include field deployment with multiple NomadicBTS based cellular network to fully tap into the inherent benefits of Software Defined and Cognitive Radio (SDCR) within the Nigerian telecommunication space. We also hope to recruit and fund postgraduate students and research fellows to carry out further studies on the project. Additional funding of the project by NCC will help in actualizing these admirable goals and turn Nigeria to a producer and exporter of wireless communications technology in this era of 4th Industrial Revolution.

References

Adetiba, E., Matthews, V.O., Daramola, S.A., Samuel, I.A., Awelewa, A.A. and Eleanya, M.E.U., 2011. Nomadic Base Station (NBS): A Software Defined Radio (SDR) based architecture for capacity enhancement in mobile communications networks. International Journal of Engineering & Technology IJET-IJENS, 11(1), pp.191-195.

Adetiba, E., Matthews, V.O., John, S.N., Popoola, S.I. and Abayomi, A. (2018). NomadicBTS: Evolving cellular communication networks with software-defined radio architecture and open-source technologies. Cogent Engineering, 5(1), p.1507465.

Frattasi, S., & Della Rosa, F. (2017). Mobile positioning and tracking: From conventional to cooperative techniques (2nd ed.). New Jersey, NJ: Wiley-IEEE Press. ISBN: 978-1-119-06881-5.