NetSim Multi-Parameter Sweeper

Software Recommended:

NetSim v13.0 (32/64 bit), DOT NET CORE SDK 3.1, Python 3.7.4

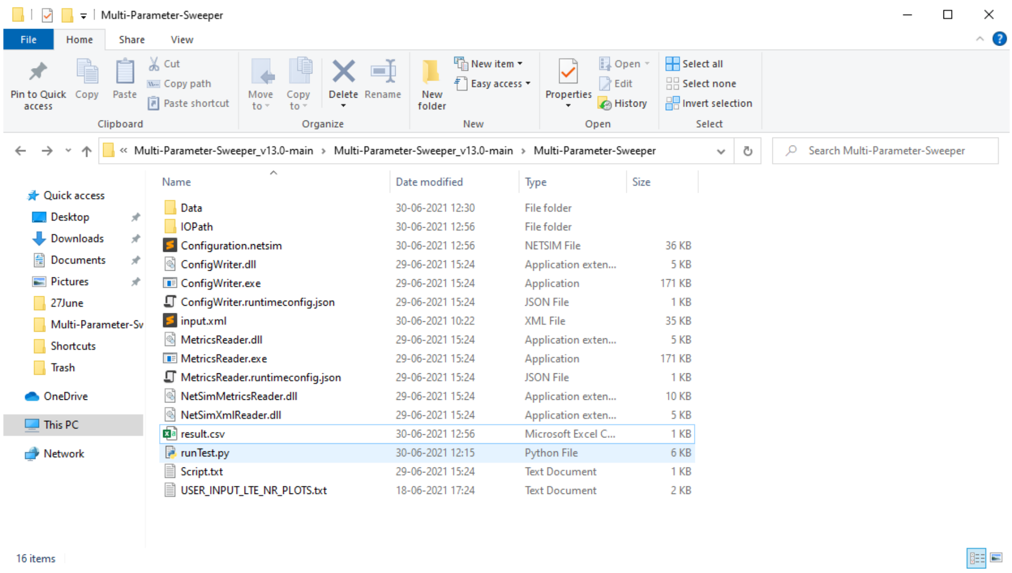
Project Download Link:

Introduction

When users want to sweep one or more parameters, they change their values between simulation runs, and compare and analyse the performance metrics from each run. NetSim multi-parameter sweeper enables users to automate the sweep process. Consider an example, where a user wishes to create and simulate a network scenario for all possible values of one or more parameters in combination and analyse a set of performance metrics across the simulation runs. This is extremely time consuming to do manually using the NetSim GUI. The multi-parameter sweep program enables users to automate the sweep process across multiple input parameters, simulate each run, save each result, and compare specific output metrics via a spreadsheet software like MS Excel. The sweep program runs NetSim via its CLI interface.

File Organization

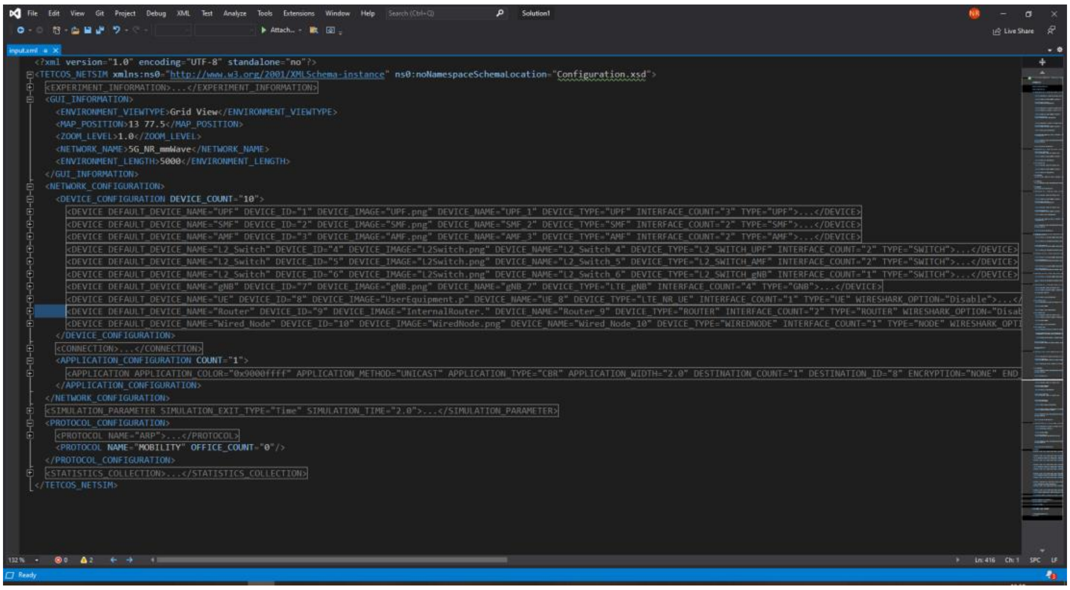
The project directory consists of several binaries which are responsible for different tasks during a multi-parameter sweep:



« Multi-Parameter-Sweeper_v13.0-main › Multi-Parameter-Sweeper_v13.0-main › Multi-Parameter-Sweeper

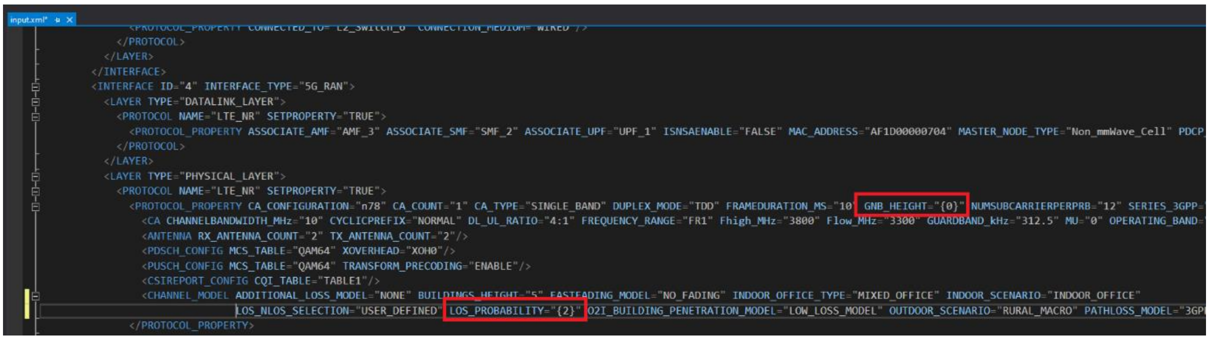
Name	Date modified	Type	Size
Data	30-06-2021 12:30	File folder	
IOPath	30-06-2021 12:56	File folder	
Configuration.netsim	30-06-2021 12:56	NETSIM File	36 KB
ConfigWriter.dll	29-06-2021 15:24	Application exten...	5 KB
ConfigWriter.exe	29-06-2021 15:24	Application	171 KB
ConfigWriter.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
input.xml	30-06-2021 10:22	XML File	35 KB
MetricsReader.dll	29-06-2021 15:24	Application exten...	5 KB
MetricsReader.exe	29-06-2021 15:24	Application	171 KB
MetricsReader.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
NetSimMetricsReader.dll	29-06-2021 15:24	Application exten...	10 KB
NetSimXmlReader.dll	29-06-2021 15:24	Application exten...	5 KB
result.csv	30-06-2021 12:56	Microsoft Excel C...	1 KB
runTest.py	30-06-2021 12:15	Python File	6 KB
Script.txt	29-06-2021 15:24	Text Document	1 KB
USER_INPUT_LTE_NR_PLOTS.txt	18-06-2021 17:24	Text Document	2 KB

input.xml: This file contains the base NetSim network configuration that is to be simulated. This file is created by copy pasting the Configuration.netsim file that can be obtained by saving a network configuration in NetSim and renaming it to input.xml.



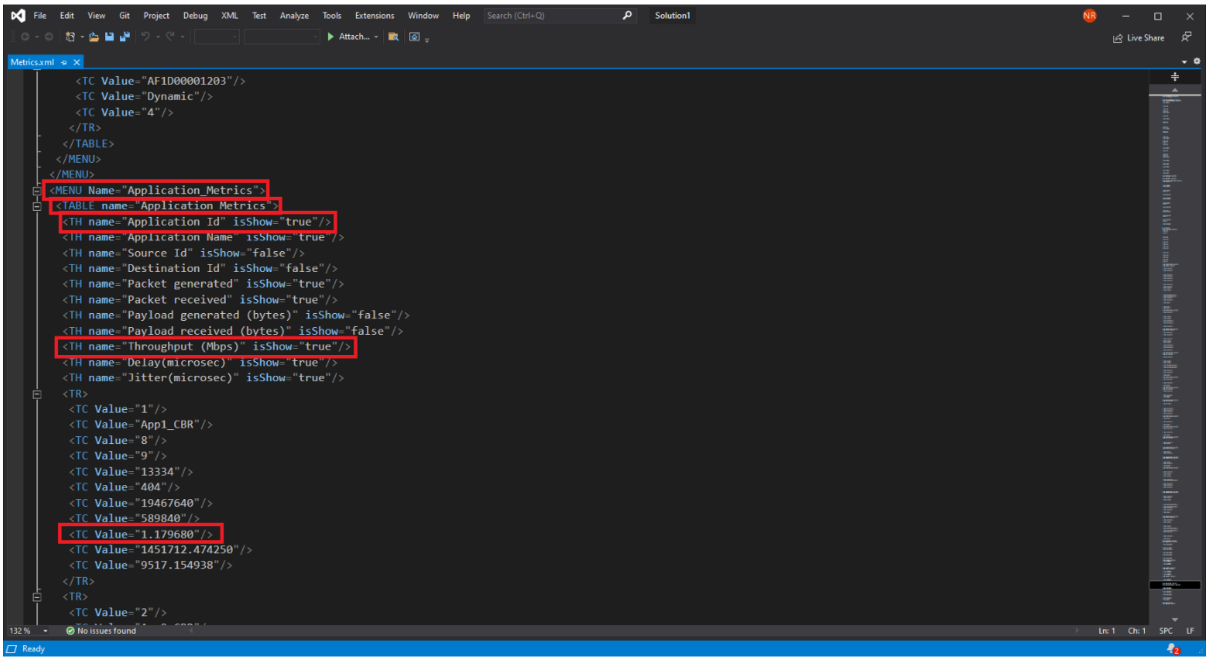
```xml
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<TETCOS_NETSIM xmlns:ns0="http://www.w3.org/2001/XMLSchema-instance" ns0:noNamespaceSchemaLocation="Configuration.xsd">
  <EXPERIMENT_INFORMATION>...</EXPERIMENT_INFORMATION>
  <GUI_INFORMATION>
    <ENVIRONMENT_VIEWTYPE>Grid View</ENVIRONMENT_VIEWTYPE>
    <MAP_POSITION>13 77.5</MAP_POSITION>
    <ZOOM_LEVEL>1.0</ZOOM_LEVEL>
    <NETWORK_NAME>5G_NR_mmWave</NETWORK_NAME>
    <ENVIRONMENT_LENGTH>5000</ENVIRONMENT_LENGTH>
  </GUI_INFORMATION>
  <NETWORK_CONFIGURATION>
    <DEVICE_CONFIGURATION DEVICE_COUNT="10">
      <DEVICE DEFAULT_DEVICE_NAME="UPF" DEVICE_ID="1" DEVICE_IMAGE="UPF.png" DEVICE_NAME="UPF_1" DEVICE_TYPE="UPF" INTERFACE_COUNT="3" TYPE="UPF">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="SMF" DEVICE_ID="2" DEVICE_IMAGE="SMF.png" DEVICE_NAME="SMF_2" DEVICE_TYPE="SMF" INTERFACE_COUNT="2" TYPE="SMF">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="AMF" DEVICE_ID="3" DEVICE_IMAGE="AMF.png" DEVICE_NAME="AMF_3" DEVICE_TYPE="AMF" INTERFACE_COUNT="2" TYPE="AMF">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="L2_Switch" DEVICE_ID="4" DEVICE_IMAGE="L2Switch.png" DEVICE_NAME="L2_Switch_4" DEVICE_TYPE="L2_SWITCH_UPF" INTERFACE_COUNT="2" TYPE="SWITCH">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="L2_Switch" DEVICE_ID="5" DEVICE_IMAGE="L2Switch.png" DEVICE_NAME="L2_Switch_5" DEVICE_TYPE="L2_SWITCH_AMF" INTERFACE_COUNT="2" TYPE="SWITCH">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="L2_Switch" DEVICE_ID="6" DEVICE_IMAGE="L2Switch.png" DEVICE_NAME="L2_Switch_6" DEVICE_TYPE="L2_SWITCH_gNB" INTERFACE_COUNT="1" TYPE="SWITCH">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="gNB" DEVICE_ID="7" DEVICE_IMAGE="gNB.png" DEVICE_NAME="gNB_7" DEVICE_TYPE="LTE_gNB" INTERFACE_COUNT="4" TYPE="GNB">...</DEVICE>
      <DEVICE DEFAULT_DEVICE_NAME="UE" DEVICE_ID="8" DEVICE_IMAGE="UserEquipment.p" DEVICE_NAME="UE_8" DEVICE_TYPE="LTE_NR_UE" INTERFACE_COUNT="1" TYPE="UE" WIRESHARK_OPTION="Disable">...</
      <DEVICE DEFAULT_DEVICE_NAME="Router" DEVICE_ID="9" DEVICE_IMAGE="InternalRouter." DEVICE_NAME="Router_9" DEVICE_TYPE="ROUTER" INTERFACE_COUNT="2" TYPE="ROUTER" WIRESHARK_OPTION="Disab
      <DEVICE DEFAULT_DEVICE_NAME="Wired_Node" DEVICE_ID="10" DEVICE_IMAGE="WiredNode.png" DEVICE_NAME="Wired_Node_10" DEVICE_TYPE="WIREDNODE" INTERFACE_COUNT="1" TYPE="NODE" WIRESHARK_OPTI
    </DEVICE_CONFIGURATION>
    <CONNECTION>...</CONNECTION>
    <APPLICATION_CONFIGURATION COUNT="1">
      <APPLICATION APPLICATION_COLOR="0x9000ffff" APPLICATION_METHOD="UNICAST" APPLICATION_TYPE="CBR" APPLICATION_WIDTH="2.0" DESTINATION_COUNT="1" DESTINATION_ID="8" ENCRYPTION="NONE" END
    </APPLICATION_CONFIGURATION>
  </NETWORK_CONFIGURATION>
  <SIMULATION_PARAMETER SIMULATION_EXIT_TYPE="Time" SIMULATION_TIME="2.0">...</SIMULATION_PARAMETER>
  <PROTOCOL_CONFIGURATION>
    <PROTOCOL NAME="ARP">...</PROTOCOL>
    <PROTOCOL NAME="MOBILITY" OFFICE_COUNT="0"/>
  </PROTOCOL_CONFIGURATION>
  <STATISTICS_COLLECTION>...</STATISTICS_COLLECTION>
</TETCOS_NETSIM>
```

The values of parameters which are to be varied during each simulation run needs to be specified as {0}, {1}, {2}, etc. respectively. For Example, if the X and Y coordinates of a device is to be varied the values can be modified in the input.xml file as shown below



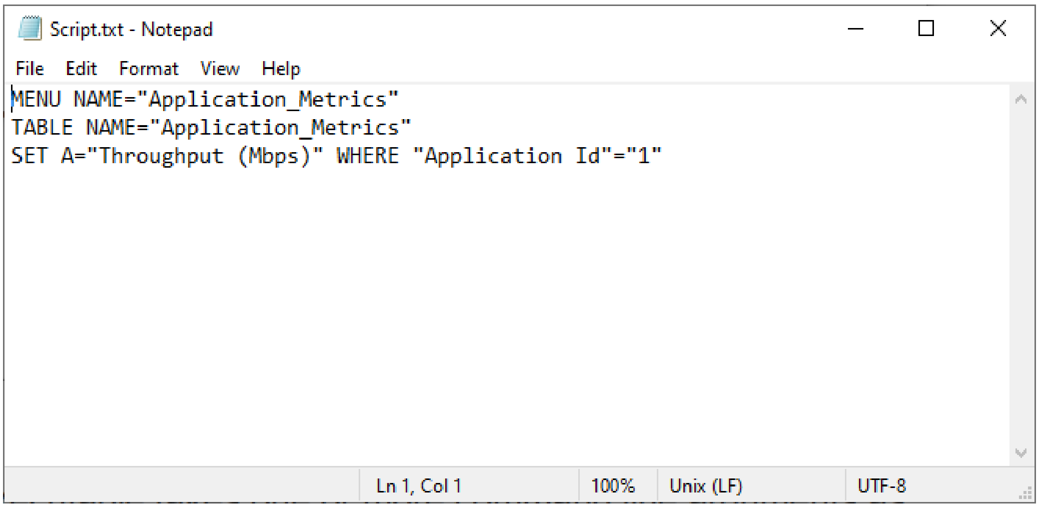
```xml
              <PROTOCOL_PROPERTY CONNECTED_TO="L2_Switch_6" CONNECTION_MEDIUM="WIRED"/>
            </PROTOCOL>
          </LAYER>
        </INTERFACE>
        <INTERFACE ID="4" INTERFACE_TYPE="5G_RAN">
          <LAYER TYPE="DATALINK_LAYER">
            <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
              <PROTOCOL_PROPERTY ASSOCIATE_AMF="AMF_3" ASSOCIATE_SMF="SMF_2" ASSOCIATE_UPF="UPF_1" ISNSAENABLE="FALSE" MAC_ADDRESS="AF1D00000704" MASTER_NODE_TYPE="Non_mmWave_Cell" PDCP_
            </PROTOCOL>
          </LAYER>
          <LAYER TYPE="PHYSICAL_LAYER">
            <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
              <PROTOCOL_PROPERTY CA_CONFIGURATION="n78" CA_COUNT="1" CA_TYPE="SINGLE_BAND" DUPLEX_MODE="TDD" FRAMEDURATION_MS="10" GNB_HEIGHT="{0}" NUMSUBCARRIERPERPRB="12" SERIES_3GPP=
                <CA CHANNELBANDWIDTH_MHz="10" CYCLICPREFIX="NORMAL" DL_UL_RATIO="4:1" FREQUENCY_RANGE="FR1" Fhigh_MHz="3800" Flow_MHz="3300" GUARDBAND_kHz="312.5" MU="0" OPERATING_BAND=
                <ANTENNA RX_ANTENNA_COUNT="2" TX_ANTENNA_COUNT="2"/>
                <PDSCH_CONFIG MCS_TABLE="QAM64" XOVERHEAD="XOH0"/>
                <PUSCH_CONFIG MCS_TABLE="QAM64" TRANSFORM_PRECODING="ENABLE"/>
                <CSIREPORT_CONFIG CQI_TABLE="TABLE1"/>
                <CHANNEL_MODEL ADDITIONAL_LOSS_MODEL="NONE" BUILDINGS_HEIGHT="5" FASTFADING_MODEL="NO_FADING" INDOOR_OFFICE_TYPE="MIXED_OFFICE" INDOOR_SCENARIO="INDOOR_OFFICE"
                               LOS_NLOS_SELECTION="USER_DEFINED" LOS_PROBABILITY="{2}" O2I_BUILDING_PENETRATION_MODEL="LOW_LOSS_MODEL" OUTDOOR_SCENARIO="RURAL_MACRO" PATHLOSS_MODEL="3GPP
              </PROTOCOL_PROPERTY>
```

Script.txt: This file should be updated with the parameter from the output metrics of NetSim that is to be logged at the end of each simulation run for the purpose of analysis. At the end of every simulation, NetSim generates a Metrics.xml file which contain the performance metrics written in a specific format based on which it is loaded in the results dashboard. Each Metric is part of a results table which can be accessed using a menu in the results dashboard. A NetSim Metrics.xml file is shown below:



```
      <TC Value="AF1D00001203"/>
      <TC Value="Dynamic"/>
      <TC Value="4"/>
     </TR>
    </TABLE>
   </MENU>
  </MENU>
  <MENU Name="Application_Metrics">
   <TABLE name="Application Metrics">
    <TH name="Application Id" isShow="true"/>
    <TH name="Application Name" isShow="true"/>
    <TH name="Source Id" isShow="false"/>
    <TH name="Destination Id" isShow="false"/>
    <TH name="Packet generated" isShow="true"/>
    <TH name="Packet received" isShow="true"/>
    <TH name="Payload generated (bytes)" isShow="false"/>
    <TH name="Payload received (bytes)" isShow="false"/>
    <TH name="Throughput (Mbps)" isShow="true"/>
    <TH name="Delay(microsec)" isShow="true"/>
    <TH name="Jitter(microsec)" isShow="true"/>
    <TR>
     <TC Value="1"/>
     <TC Value="App1_CBR"/>
     <TC Value="8"/>
     <TC Value="9"/>
     <TC Value="13334"/>
     <TC Value="404"/>
     <TC Value="19467640"/>
     <TC Value="589840"/>
     <TC Value="1.179680"/>
     <TC Value="1451712.474250"/>
     <TC Value="9517.154938"/>
    </TR>
    <TR>
     <TC Value="2"/>
```

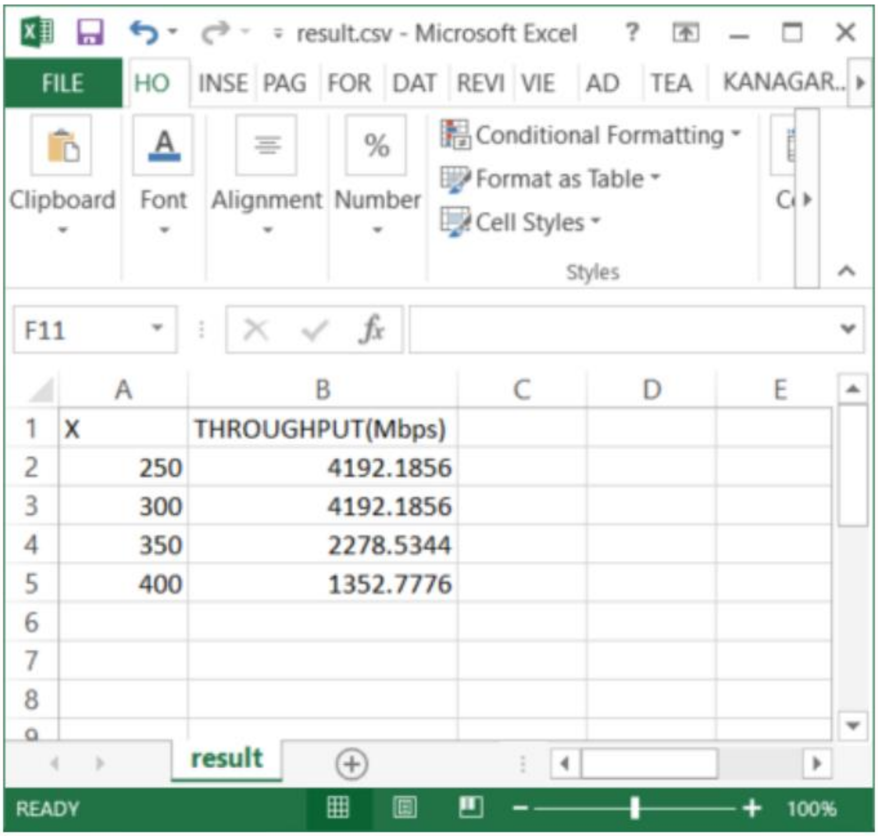
For Example, if the application throughput is to be logged for each simulation run then the scrip file can be updated as shown below:



```
MENU NAME="Application_Metrics"
TABLE NAME="Application_Metrics"
SET A="Throughput (Mbps)" WHERE "Application Id"="1"
```

ConfigWriter.exe: This executable takes one or more command line arguments as input and generated Configuration.netsim file by replacing the arguments in place of the variable parameters specified in the input.xml file. If there are two variable parameters specified in the input.xml file ({0} and {1}) then two arguments need to be passed while calling ConfigWriter.exe.

MetricsReader.exe: This executable is responsible for reading the output parameter from the Metrics.xml file generated after each simulation and logging it to the results file. Users the Script.txt file to determine which parameter to read from the Metrics file. If multiple parameters are to be read and logged, then the MetricsReader.exe can be called multiple times with Script.txt file having information about the parameter to be read each time.



	A	B
1	X	THROUGHPUT(Mbps)
2	250	4192.1856
3	300	4192.1856
4	350	2278.5344
5	400	1352.7776

Supporting DLL's: Some the supporting files such as ConfigWriter.dll, MetricsReader.dll, NetSimMetricsReader.dll, NetSimXmlReader.dll, etc. which are present in the project folder are used by other executable such as ConfigWriter.exe and MetricsReader.exe for various purposes during a multi-parameter sweep.

runTest script files: The files runTest.bat, runTest.py are the main script files that can be used to start a multi-parameter sweep process. Both files differ in the programming language used for the script.

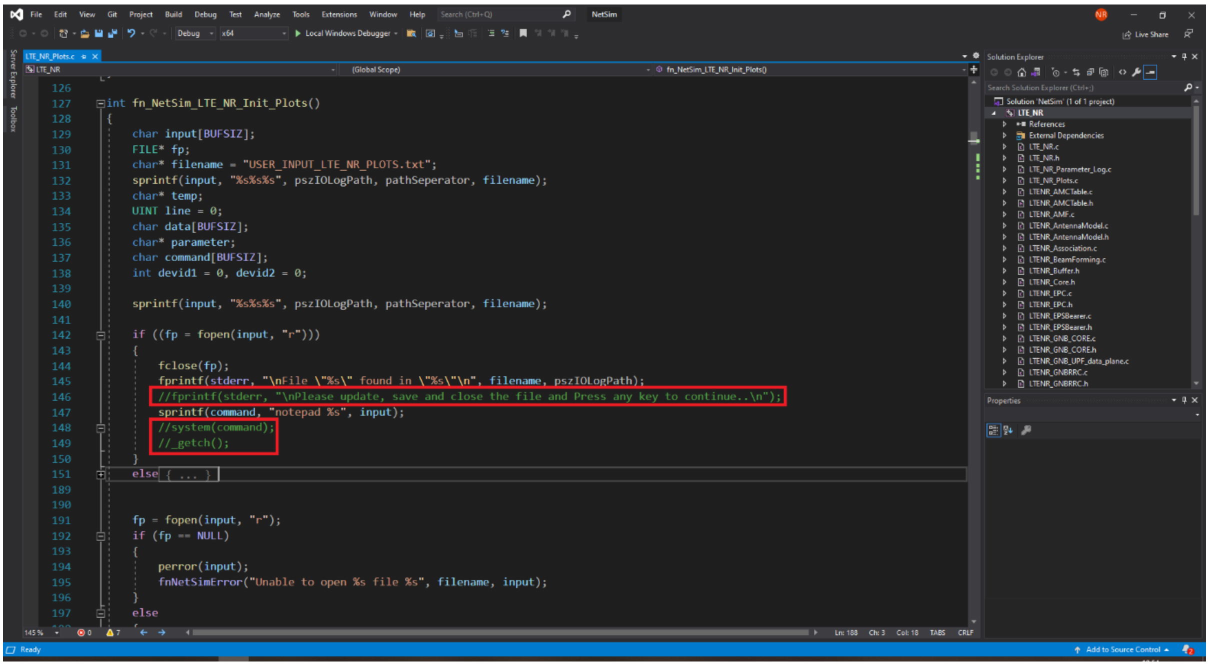
runTest.bat uses Windows commands that can be executed by the windows command line interpreter. Batch scripts may get complex as the number of input and output parameters increases.

runTest.py uses python programming language which is less complex and offers more flexibility as the number of input and output parameters increases. Users can also write the script to run the multi-parameter sweep process in a preferred programming language as per the convenience. The script runs multiple simulation iterations based on the number of parameters to be varied and the range of values of each parameter.

Additional Settings done in NetSim Source Code for the instrumented workspace:

The following lines of code were commented in the fn_NetSim_LTE_NR_Init_Plots() in LTE_NR_Plots.c file to avoid the user interaction during the parameter sweep process:

```
//fprintf(stderr, "\nPlease update, save and close the file and Press any key to continue..\n");
//system(command);
//_getch();
```

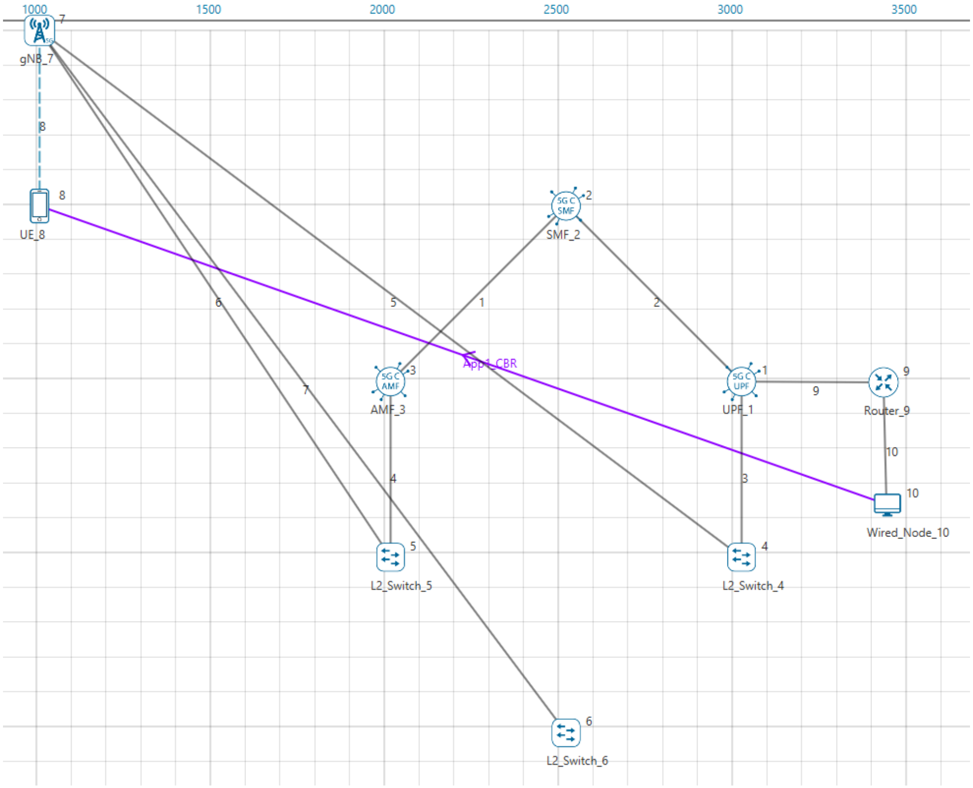


```c
int fn_NetSim_LTE_NR_Init_Plots()
{
    char input[BUFSIZ];
    FILE* fp;
    char* filename = "USER_INPUT_LTE_NR_PLOTS.txt";
    sprintf(input, "%s%s%s", pszIOLogPath, pathSeperator, filename);
    char* temp;
    UINT line = 0;
    char data[BUFSIZ];
    char* parameter;
    char command[BUFSIZ];
    int devid1 = 0, devid2 = 0;

    sprintf(input, "%s%s%s", pszIOLogPath, pathSeperator, filename);

    if ((fp = fopen(input, "r")))
    {
        fclose(fp);
        fprintf(stderr, "\nFile \"%s\" found in \"%s\"\n", filename, pszIOLogPath);
        //fprintf(stderr, "\nPlease update, save and close the file and Press any key to continue..\n");
        sprintf(command, "notepad %s", input);
        //system(command);
        //_getch();
    }
    else { ... }


    fp = fopen(input, "r");
    if (fp == NULL)
    {
        perror(input);
        fnNetSimError("Unable to open %s file %s", filename, input);
    }
    else
```

Running a Multi-Parameter Sweep process:

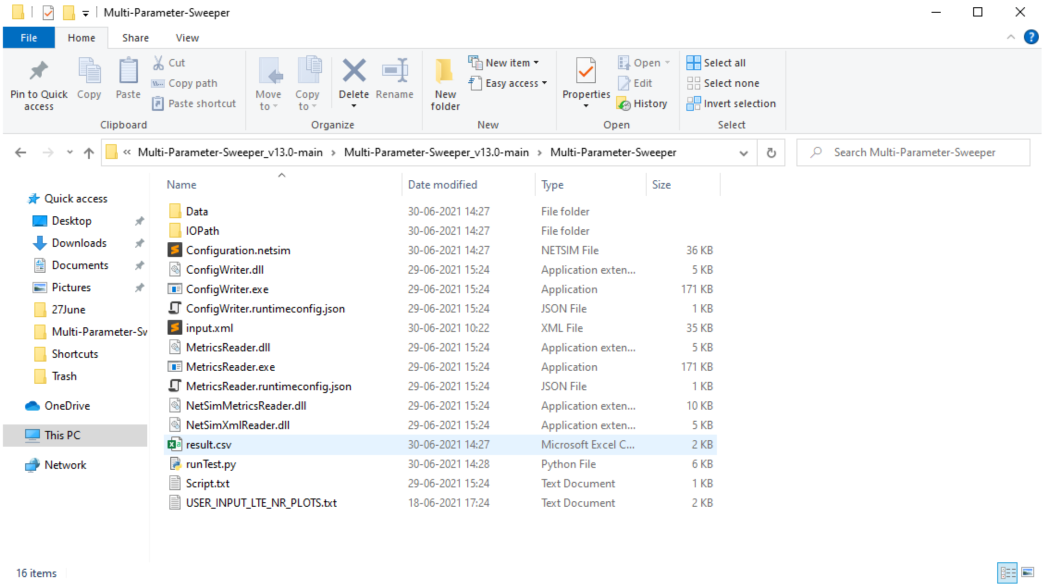
Experiment-2: MIMO Beamforming in 5G: A start with MISO and SIMO

Consider the following network 5G network scenario in NetSim, comprising of a Wired Node, Router, gNB and a UE.



The network configuration has the initial distance between the gNB and UE as 2km with the gNB located at (400,0) and UE located at (400,2000). Multi-Parameter Sweeper is configured to run simulations for different Antenna Counts for both Input and Output in the gNB and UE.

1. The network scenario is saved and the content of the Configuration.netsim file is copied to the Multi-Parameter-Sweeper directory and renamed as input.xml. Refer to the Experiment 2 directory which is part of the project folder (Multi-ParameterSweeper_v13.0\Examples\ Experiment-2)

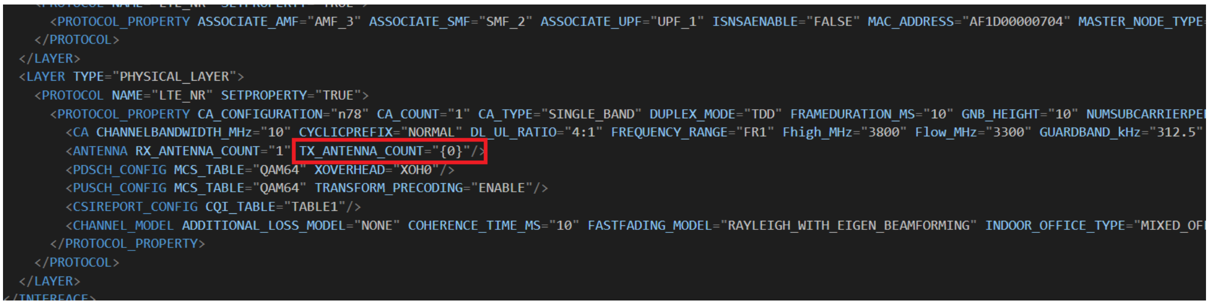


« Multi-Parameter-Sweeper_v13.0-main › Multi-Parameter-Sweeper_v13.0-main › Multi-Parameter-Sweeper

Name	Date modified	Type	Size
Data	30-06-2021 14:27	File folder	
IOPath	30-06-2021 14:27	File folder	
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ConfigWriter.dll	29-06-2021 15:24	Application exten...	5 KB
ConfigWriter.exe	29-06-2021 15:24	Application	171 KB
ConfigWriter.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
input.xml	30-06-2021 10:22	XML File	35 KB
MetricsReader.dll	29-06-2021 15:24	Application exten...	5 KB
MetricsReader.exe	29-06-2021 15:24	Application	171 KB
MetricsReader.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
NetSimMetricsReader.dll	29-06-2021 15:24	Application exten...	10 KB
NetSimXmlReader.dll	29-06-2021 15:24	Application exten...	5 KB
result.csv	30-06-2021 14:27	Microsoft Excel C...	2 KB
runTest.py	30-06-2021 14:28	Python File	6 KB
Script.txt	29-06-2021 15:24	Text Document	1 KB
USER_INPUT_LTE_NR_PLOTS.txt	18-06-2021 17:24	Text Document	2 KB

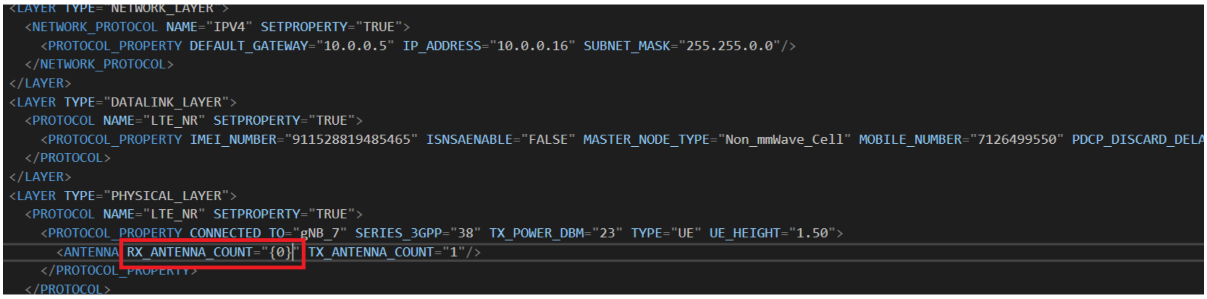
16 items

2. The value of the Tx Antenna Count of gNB that is to be modified during each simulation run is updated (“{0}”) for MISO in the configuration file as shown below:



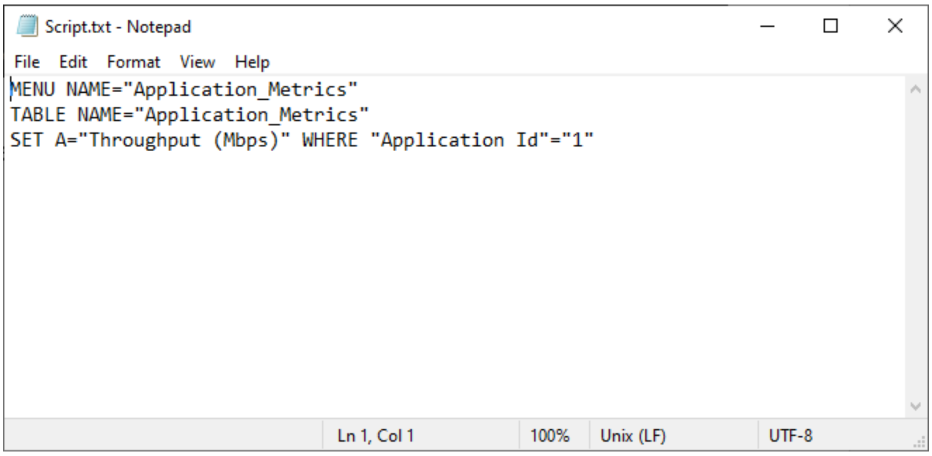
```
      <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
        <PROTOCOL_PROPERTY ASSOCIATE_AMF="AMF_3" ASSOCIATE_SMF="SMF_2" ASSOCIATE_UPF="UPF_1" ISNSAENABLE="FALSE" MAC_ADDRESS="AF1D00000704" MASTER_NODE_TYPE
      </PROTOCOL>
    </LAYER>
    <LAYER TYPE="PHYSICAL_LAYER">
      <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
        <PROTOCOL_PROPERTY CA_CONFIGURATION="n78" CA_COUNT="1" CA_TYPE="SINGLE_BAND" DUPLEX_MODE="TDD" FRAMEDURATION_MS="10" GNB_HEIGHT="10" NUMSUBCARRIERPE
          <CA CHANNELBANDWIDTH_MHz="10" CYCLICPREFIX="NORMAL" DL_UL_RATIO="4:1" FREQUENCY_RANGE="FR1" Fhigh_MHz="3800" Flow_MHz="3300" GUARDBAND_kHz="312.5"
          <ANTENNA RX_ANTENNA_COUNT="1" TX_ANTENNA_COUNT="{0}"/>
          <PDSCH_CONFIG MCS_TABLE="QAM64" XOVERHEAD="XOH0"/>
          <PUSCH_CONFIG MCS_TABLE="QAM64" TRANSFORM_PRECODING="ENABLE"/>
          <CSIREPORT_CONFIG CQI_TABLE="TABLE1"/>
          <CHANNEL_MODEL ADDITIONAL_LOSS_MODEL="NONE" COHERENCE_TIME_MS="10" FASTFADING_MODEL="RAYLEIGH_WITH_EIGEN_BEAMFORMING" INDOOR_OFFICE_TYPE="MIXED_OF
        </PROTOCOL_PROPERTY>
      </PROTOCOL>
    </LAYER>
  </INTERFACE>
```

And Rx Antenna Count of UE for SIMO in the configuration file as shown below:



```
<LAYER TYPE="NETWORK_LAYER">
  <NETWORK_PROTOCOL NAME="IPV4" SETPROPERTY="TRUE">
    <PROTOCOL_PROPERTY DEFAULT_GATEWAY="10.0.0.5" IP_ADDRESS="10.0.0.16" SUBNET_MASK="255.255.0.0"/>
  </NETWORK_PROTOCOL>
</LAYER>
<LAYER TYPE="DATALINK_LAYER">
  <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
    <PROTOCOL_PROPERTY IMEI_NUMBER="911528819485465" ISNSAENABLE="FALSE" MASTER_NODE_TYPE="Non_mmWave_Cell" MOBILE_NUMBER="7126499550" PDCP_DISCARD_DELA
  </PROTOCOL>
</LAYER>
<LAYER TYPE="PHYSICAL_LAYER">
  <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
    <PROTOCOL_PROPERTY CONNECTED_TO="gNB_7" SERIES_3GPP="38" TX_POWER_DBM="23" TYPE="UE" UE_HEIGHT="1.50">
      <ANTENNA RX_ANTENNA_COUNT="{0}" TX_ANTENNA_COUNT="1"/>
    </PROTOCOL_PROPERTY>
  </PROTOCOL>
```

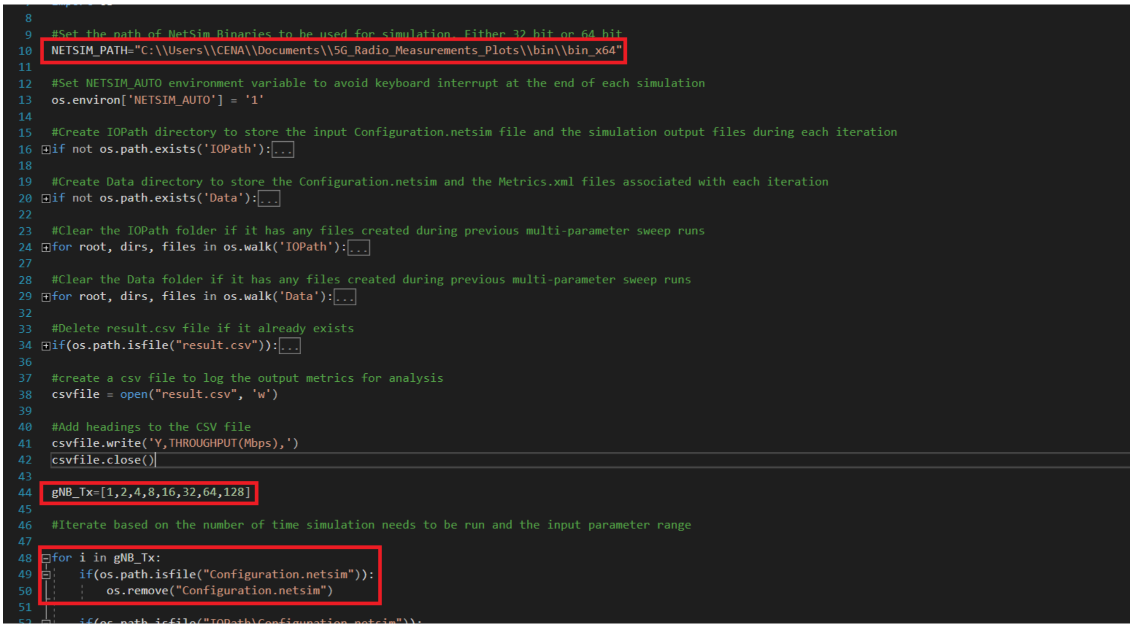
3. The Script.txt file is updated with the details of the output parameter to be read from the Metrics.xml file and added to the result csv log file. In this case the Application throughput is to be logged for each simulation run



```
MENU NAME="Application_Metrics"
TABLE NAME="Application_Metrics"
SET A="Throughput (Mbps)" WHERE "Application Id"="1"
```

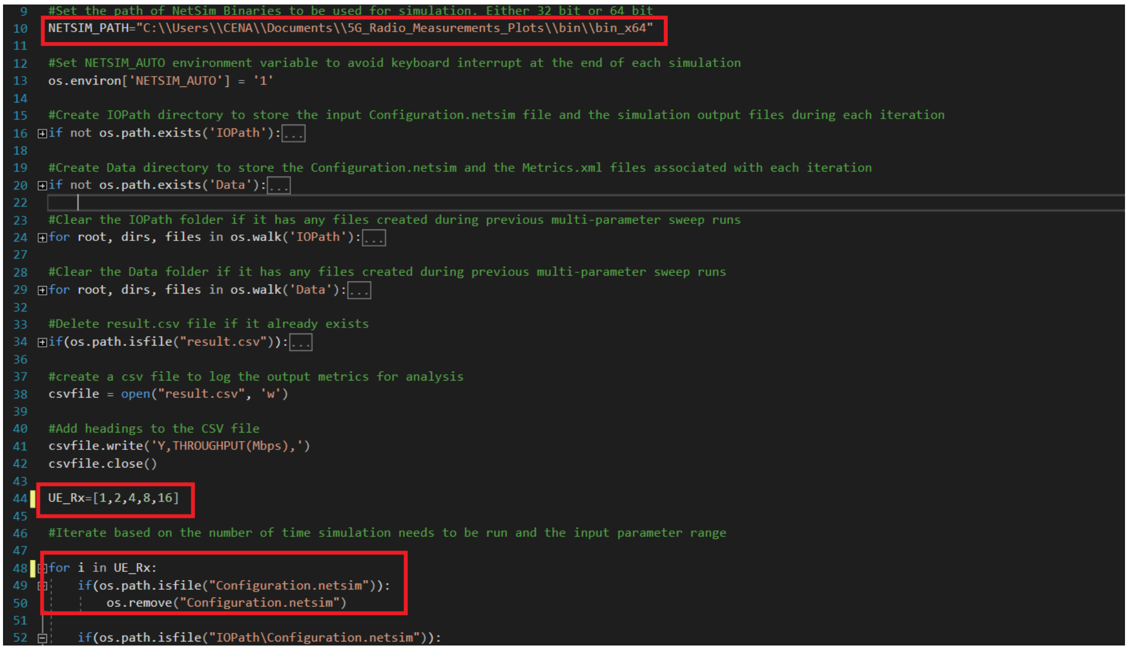
4. runTest.py is updated to pass the gNB Tx Antenna Count value in the case of MISO, and UE Rx Antenna Height value in case of SIMO during each iteration to generate Configuration file run simulation and update the result csv log.

MISO:



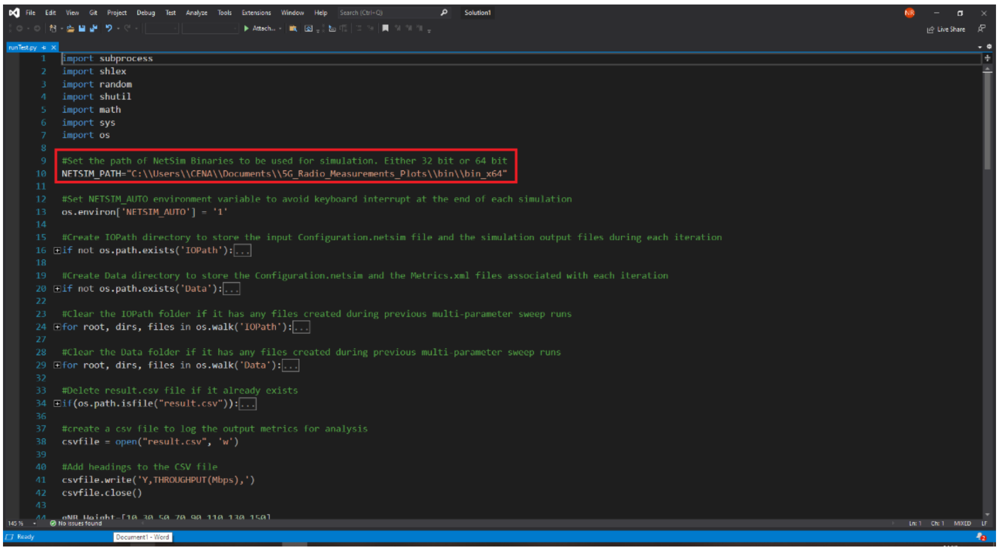
```
#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Tx=[1,2,4,8,16,32,64,128]

#Iterate based on the number of time simulation needs to be run and the input parameter range

for i in gNB_Tx:
    if(os.path.isfile("Configuration.netsim")):
        os.remove("Configuration.netsim")

    if(os.path.isfile("IOPath\Configuration.netsim")):
```

SIMO:



```python
#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

UE_Rx=[1,2,4,8,16]

#Iterate based on the number of time simulation needs to be run and the input parameter range

for i in UE_Rx:
    if(os.path.isfile("Configuration.netsim")):
        os.remove("Configuration.netsim")

    if(os.path.isfile("IOPath\Configuration.netsim")):
```

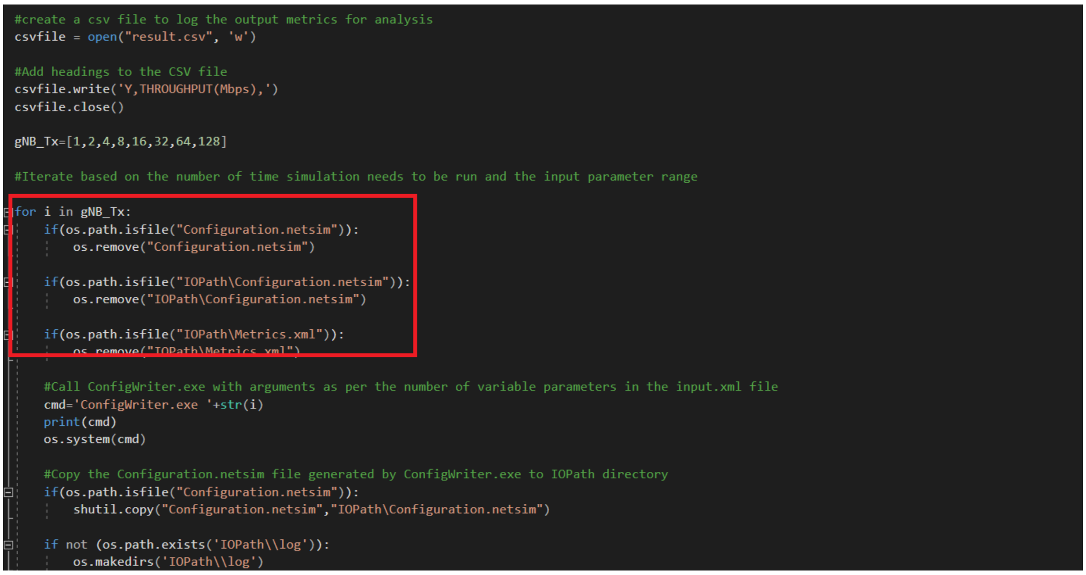
- NETSIM_PATH variable is set to the path of NetSim 32-bit/64-bit binaries in the install directory or workspace in the system.



```python
import subprocess
import shlex
import random
import shutil
import math
import sys
import os

#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Height=[10,30,50,70,90,110,130,150]
```

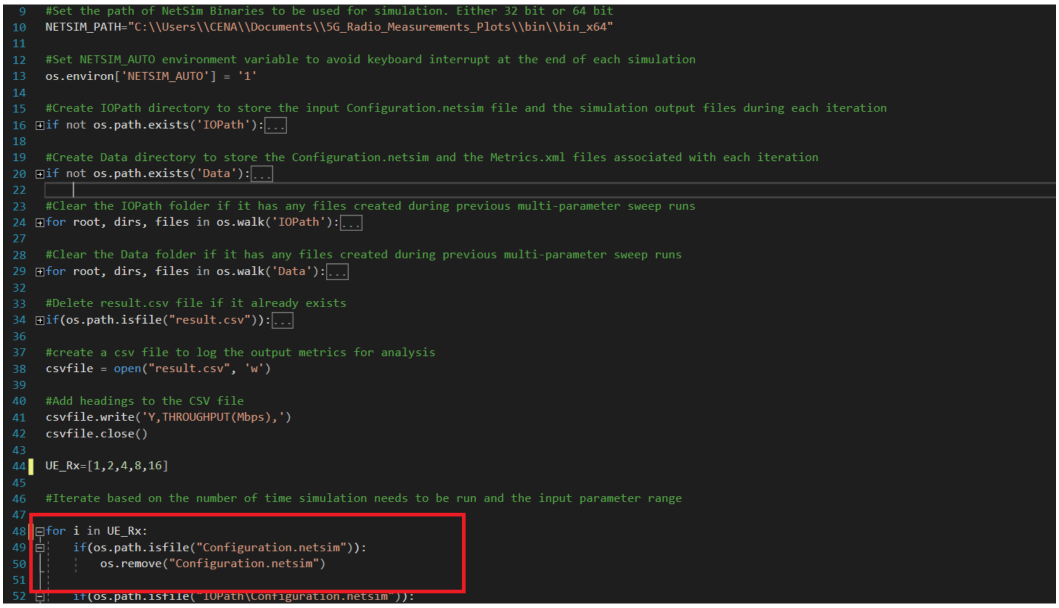
- A result.csv file is created and added with headings Y and Throughput(Mbps)
- For loop is set to iteratively run simulations for values of gNB TX Antenna Count starting from 1 to 128 in MISO and UE Rx Antenna Count from 1 to 16 in SIMO.

MISO:



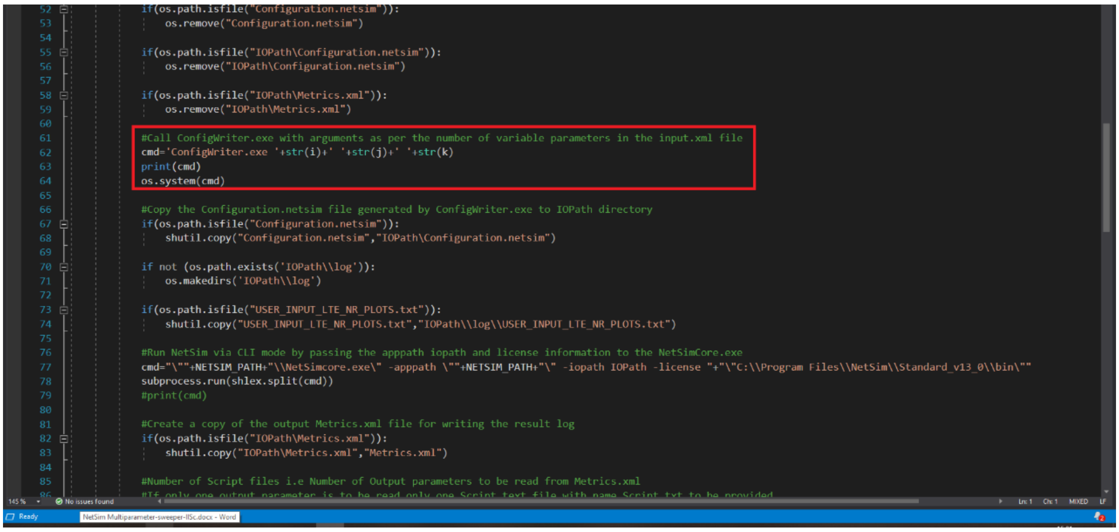
```
#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Tx=[1,2,4,8,16,32,64,128]

#Iterate based on the number of time simulation needs to be run and the input parameter range

for i in gNB_Tx:
    if(os.path.isfile("Configuration.netsim")):
        os.remove("Configuration.netsim")

    if(os.path.isfile("IOPath\Configuration.netsim")):
        os.remove("IOPath\Configuration.netsim")

    if(os.path.isfile("IOPath\Metrics.xml")):
        os.remove("IOPath\Metrics.xml")

    #Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
    cmd='ConfigWriter.exe '+str(i)
    print(cmd)
    os.system(cmd)

    #Copy the Configuration.netsim file generated by ConfigWriter.exe to IOPath directory
    if(os.path.isfile("Configuration.netsim")):
        shutil.copy("Configuration.netsim","IOPath\Configuration.netsim")

    if not (os.path.exists('IOPath\\log')):
        os.makedirs('IOPath\\log')
```

SIMO:



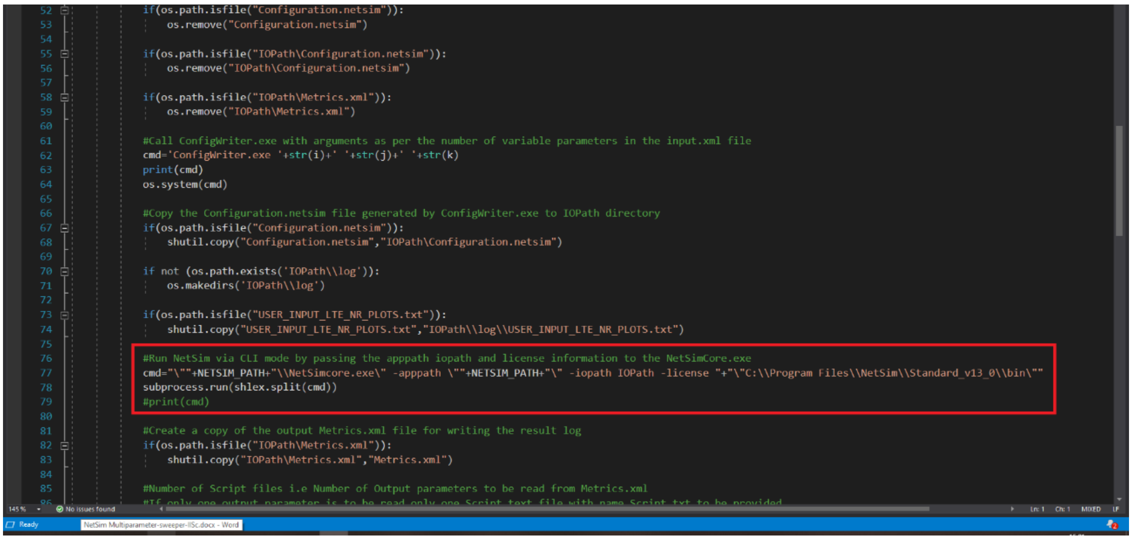
```
#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

UE_Rx=[1,2,4,8,16]

#Iterate based on the number of time simulation needs to be run and the input parameter range

for i in UE_Rx:
    if(os.path.isfile("Configuration.netsim")):
        os.remove("Configuration.netsim")

    if(os.path.isfile("IOPath\Configuration.netsim")):
```

- The value of the parameters gNB Tx Antenna Count for MISO and UE Rx Antenna Count for SIMO in the current iteration is written to the result log file for analysis.
- The value of the parameters in the current iteration is passed as input to ConfigWriter executable to generate Configuration.netsim file for each simulation.



```
if(os.path.isfile("Configuration.netsim")):
    os.remove("Configuration.netsim")

if(os.path.isfile("IOPath\Configuration.netsim")):
    os.remove("IOPath\Configuration.netsim")

if(os.path.isfile("IOPath\Metrics.xml")):
    os.remove("IOPath\Metrics.xml")

#Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
cmd='ConfigWriter.exe '+str(i)+' '+str(j)+' '+str(k)
print(cmd)
os.system(cmd)

#Copy the Configuration.netsim file generated by ConfigWriter.exe to IOPath directory
if(os.path.isfile("Configuration.netsim")):
    shutil.copy("Configuration.netsim","IOPath\Configuration.netsim")

if not (os.path.exists('IOPath\\log')):
    os.makedirs('IOPath\\log')

if(os.path.isfile("USER_INPUT_LTE_NR_PLOTS.txt")):
    shutil.copy("USER_INPUT_LTE_NR_PLOTS.txt","IOPath\\log\\USER_INPUT_LTE_NR_PLOTS.txt")

#Run NetSim via CLI mode by passing the apppath iopath and license information to the NetSimCore.exe
cmd="\""+NETSIM_PATH+"\\NetSimcore.exe\" -apppath \""+NETSIM_PATH+"\" -iopath IOPath -license "+"\"C:\\Program Files\\NetSim\\Standard_v13_0\\bin\""
subprocess.run(shlex.split(cmd))
#print(cmd)

#Create a copy of the output Metrics.xml file for writing the result log
if(os.path.isfile("IOPath\Metrics.xml")):
    shutil.copy("IOPath\Metrics.xml","Metrics.xml")

#Number of Script files i.e Number of Output parameters to be read from Metrics.xml
#If only one output parameter is to be read only one Script text file with name Script.txt to be provided
```

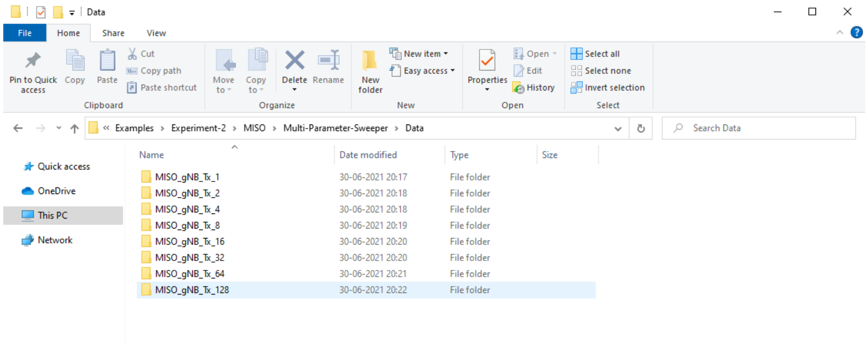
- NetSim simulation is run via CLI mode by passing the apppath, iopath and license server information.



```
if(os.path.isfile("Configuration.netsim")):
    os.remove("Configuration.netsim")

if(os.path.isfile("IOPath\Configuration.netsim")):
    os.remove("IOPath\Configuration.netsim")

if(os.path.isfile("IOPath\Metrics.xml")):
    os.remove("IOPath\Metrics.xml")

#Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
cmd='ConfigWriter.exe '+str(i)+' '+str(j)+' '+str(k)
print(cmd)
os.system(cmd)

#Copy the Configuration.netsim file generated by ConfigWriter.exe to IOPath directory
if(os.path.isfile("Configuration.netsim")):
    shutil.copy("Configuration.netsim","IOPath\Configuration.netsim")

if not (os.path.exists('IOPath\\log')):
    os.makedirs('IOPath\\log')

if(os.path.isfile("USER_INPUT_LTE_NR_PLOTS.txt")):
    shutil.copy("USER_INPUT_LTE_NR_PLOTS.txt","IOPath\\log\\USER_INPUT_LTE_NR_PLOTS.txt")

#Run NetSim via CLI mode by passing the apppath iopath and license information to the NetSimCore.exe
cmd="\""+NETSIM_PATH+"\\NetSimcore.exe\" -apppath \""+NETSIM_PATH+"\" -iopath IOPath -license "+"\"C:\\Program Files\\NetSim\\Standard_v13_0\\bin\""
subprocess.run(shlex.split(cmd))
#print(cmd)

#Create a copy of the output Metrics.xml file for writing the result log
if(os.path.isfile("IOPath\Metrics.xml")):
    shutil.copy("IOPath\Metrics.xml","Metrics.xml")

#Number of Script files i.e Number of Output parameters to be read from Metrics.xml
#If only one output parameter is to be read only one Script text file with name Script.txt to be provided
```

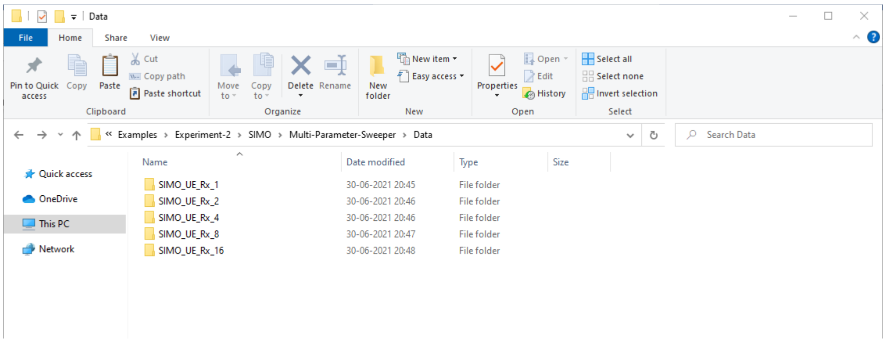
- Configuration file and Metrics file are copied and stored in folders appending the value of the parameter in the current iteration.

MISO:



Name	Date modified	Type	Size
MISO_gNB_Tx_1	30-06-2021 20:17	File folder	
MISO_gNB_Tx_2	30-06-2021 20:18	File folder	
MISO_gNB_Tx_4	30-06-2021 20:18	File folder	
MISO_gNB_Tx_8	30-06-2021 20:19	File folder	
MISO_gNB_Tx_16	30-06-2021 20:20	File folder	
MISO_gNB_Tx_32	30-06-2021 20:20	File folder	
MISO_gNB_Tx_64	30-06-2021 20:21	File folder	
MISO_gNB_Tx_128	30-06-2021 20:22	File folder	

SIMO:

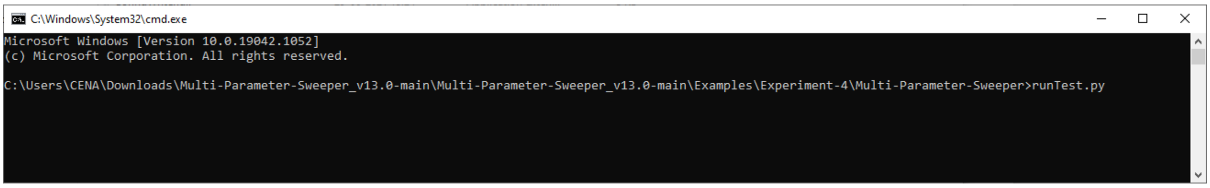


« Examples › Experiment-2 › SIMO › Multi-Parameter-Sweeper › Data

Name	Date modified	Type	Size
SIMO_UE_Rx_1	30-06-2021 20:45	File folder	
SIMO_UE_Rx_2	30-06-2021 20:46	File folder	
SIMO_UE_Rx_4	30-06-2021 20:46	File folder	
SIMO_UE_Rx_8	30-06-2021 20:47	File folder	
SIMO_UE_Rx_16	30-06-2021 20:48	File folder	

5. Multi-Parameter Sweeping process is started by opening command prompt in the directory of the Multi-Parameter-Sweeping project and starting the batch script or the python script as shown below:

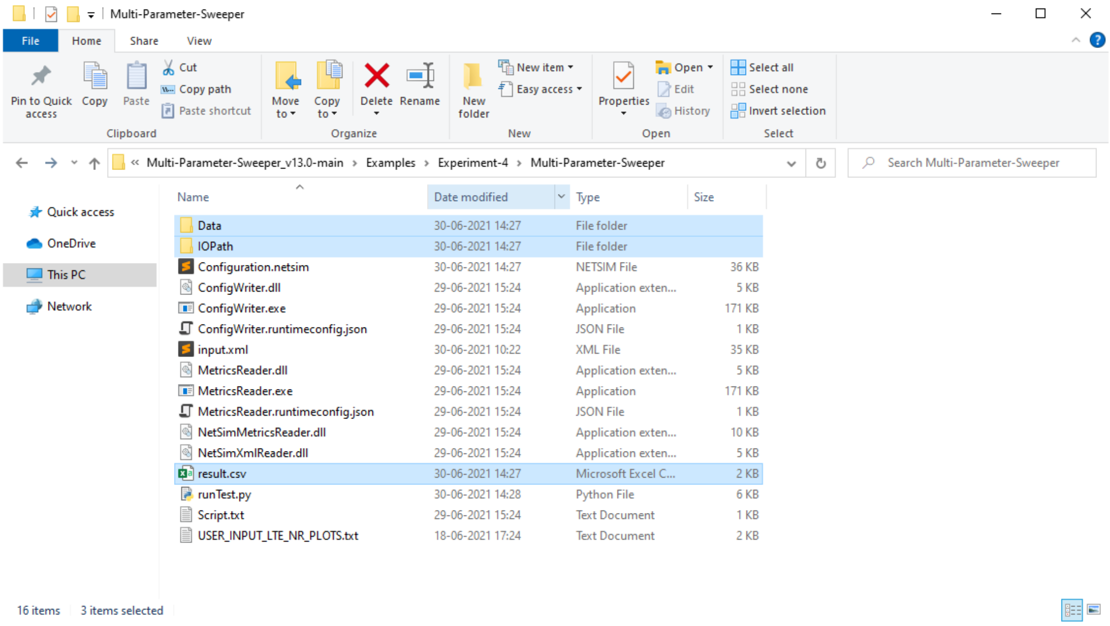
Python Script:



```
Microsoft Windows [Version 10.0.19042.1052]
(c) Microsoft Corporation. All rights reserved.

C:\Users\CENA\Downloads\Multi-Parameter-Sweeper_v13.0-main\Multi-Parameter-Sweeper_v13.0-main\Examples\Experiment-4\Multi-Parameter-Sweeper>runTest.py
```

This starts the Multi-Parameter-Sweeping process which runs NetSim simulations iteratively for different values of parameters configured. The USER_INPUT_LTE_NR_PLOTS.txt file used as input is placed in the Multiparameter sweep directory.

At the end of the process the Multi-Parameter-Sweeping folder will have the following file and folders created:

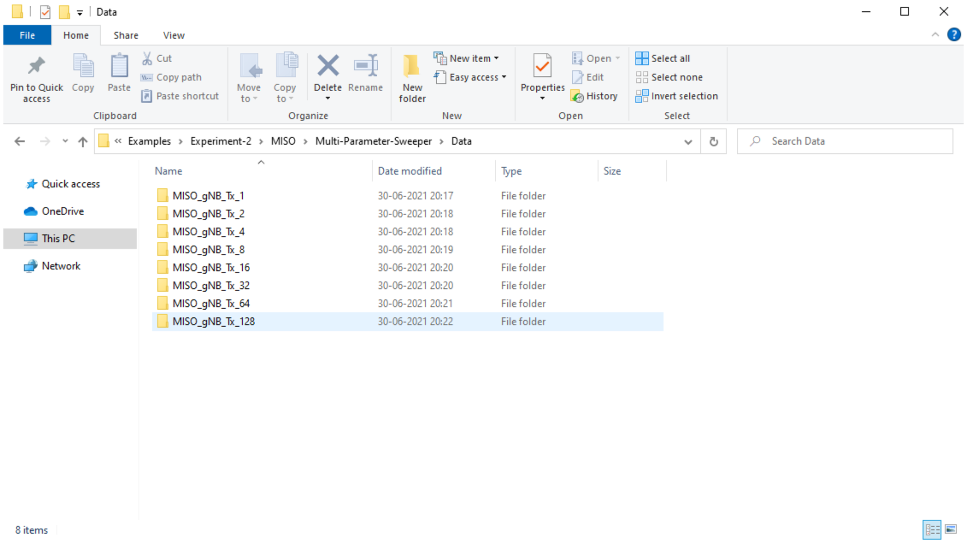


« Multi-Parameter-Sweeper_v13.0-main › Examples › Experiment-4 › Multi-Parameter-Sweeper

Name	Date modified	Type	Size
Data	30-06-2021 14:27	File folder	
IOPath	30-06-2021 14:27	File folder	
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ConfigWriter.dll	29-06-2021 15:24	Application exten...	5 KB
ConfigWriter.exe	29-06-2021 15:24	Application	171 KB
ConfigWriter.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
input.xml	30-06-2021 10:22	XML File	35 KB
MetricsReader.dll	29-06-2021 15:24	Application exten...	5 KB
MetricsReader.exe	29-06-2021 15:24	Application	171 KB
MetricsReader.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
NetSimMetricsReader.dll	29-06-2021 15:24	Application exten...	10 KB
NetSimXmlReader.dll	29-06-2021 15:24	Application exten...	5 KB
result.csv	30-06-2021 14:27	Microsoft Excel C...	2 KB
runTest.py	30-06-2021 14:28	Python File	6 KB
Script.txt	29-06-2021 15:24	Text Document	1 KB
USER_INPUT_LTE_NR_PLOTS.txt	18-06-2021 17:24	Text Document	2 KB

16 items 3 items selected

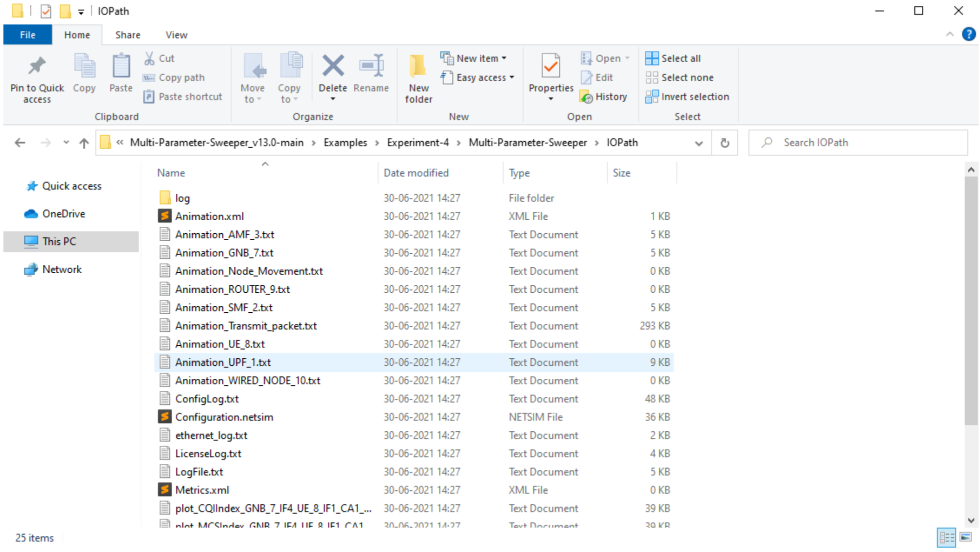
a. **Data:** The Data directory contains folders which contains the Configuration.netsim and the Metrics.xml files associated with each simulation run, including the value of the parameter in the folder name.



« Examples › Experiment-2 › MISO › Multi-Parameter-Sweeper › Data

Name	Date modified	Type	Size
MISO_gNB_Tx_1	30-06-2021 20:17	File folder	
MISO_gNB_Tx_2	30-06-2021 20:18	File folder	
MISO_gNB_Tx_4	30-06-2021 20:18	File folder	
MISO_gNB_Tx_8	30-06-2021 20:19	File folder	
MISO_gNB_Tx_16	30-06-2021 20:20	File folder	
MISO_gNB_Tx_32	30-06-2021 20:20	File folder	
MISO_gNB_Tx_64	30-06-2021 20:21	File folder	
MISO_gNB_Tx_128	30-06-2021 20:22	File folder	

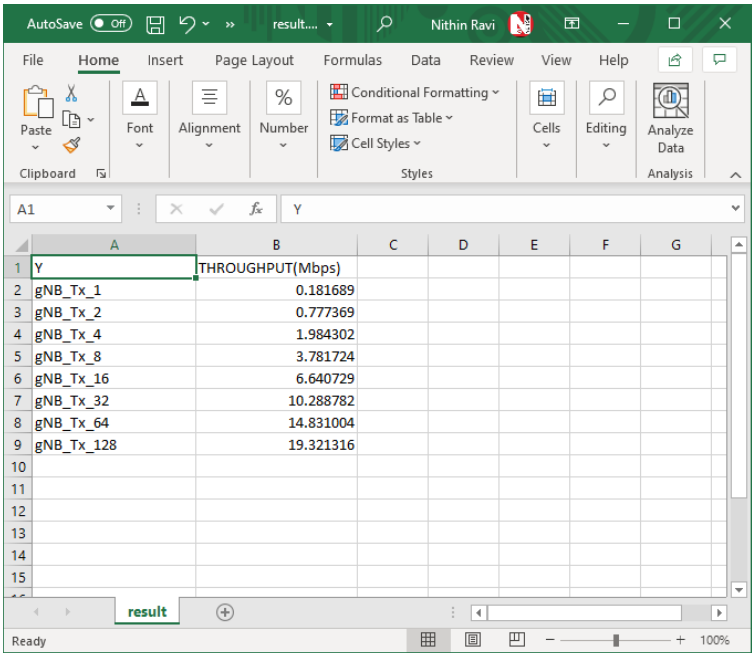
b. **IOPath:** Used for storing the Configuration.netsim file and the simulation files generated during each simulation run.



« Multi-Parameter-Sweeper_v13.0-main › Examples › Experiment-4 › Multi-Parameter-Sweeper › IOPath

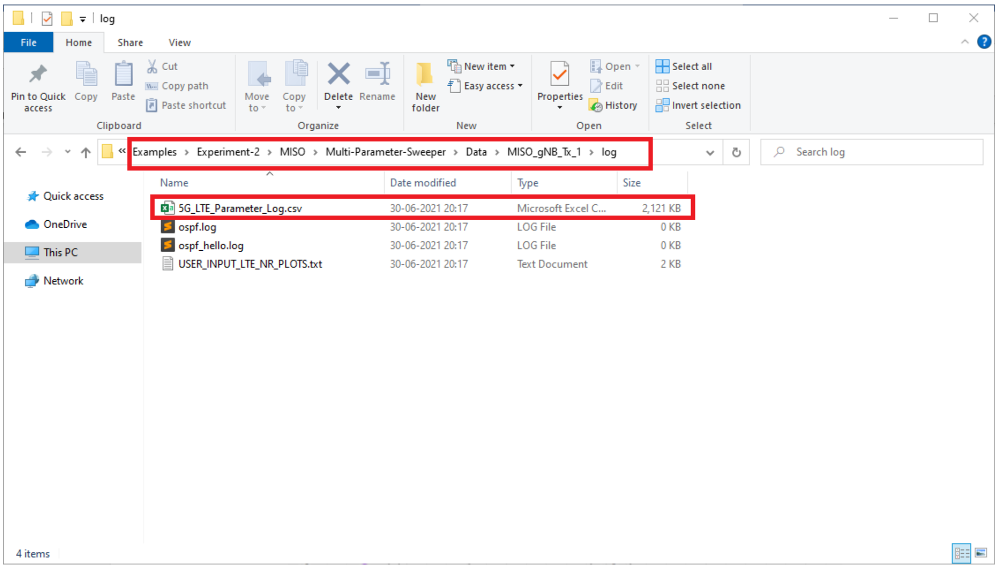
Name	Date modified	Type	Size
log	30-06-2021 14:27	File folder	
Animation.xml	30-06-2021 14:27	XML File	1 KB
Animation_AMF_3.txt	30-06-2021 14:27	Text Document	5 KB
Animation_GNB_7.txt	30-06-2021 14:27	Text Document	5 KB
Animation_Node_Movement.txt	30-06-2021 14:27	Text Document	0 KB
Animation_ROUTER_9.txt	30-06-2021 14:27	Text Document	0 KB
Animation_SMF_2.txt	30-06-2021 14:27	Text Document	5 KB
Animation_Transmit_packet.txt	30-06-2021 14:27	Text Document	293 KB
Animation_UE_8.txt	30-06-2021 14:27	Text Document	0 KB
Animation_UPF_1.txt	30-06-2021 14:27	Text Document	9 KB
Animation_WIRED_NODE_10.txt	30-06-2021 14:27	Text Document	0 KB
ConfigLog.txt	30-06-2021 14:27	Text Document	48 KB
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ethernet_log.txt	30-06-2021 14:27	Text Document	2 KB
LicenseLog.txt	30-06-2021 14:27	Text Document	4 KB
LogFile.txt	30-06-2021 14:27	Text Document	5 KB
Metrics.xml	30-06-2021 14:27	XML File	0 KB
plot_CQIIndex_GNB_7_IF4_UE_8_IF1_CA1_...	30-06-2021 14:27	Text Document	39 KB
plot_MCSIndex_GNB_7_IF4_UE_8_IF1_CA1	30-06-2021 14:27	Text Document	39 KB

c. **Result.csv:** This is the output log which contains the parameter varied during each simulation run and the output parameter associated with each run.



Y	THROUGHPUT(Mbps)
gNB_Tx_1	0.181689
gNB_Tx_2	0.777369
gNB_Tx_4	1.984302
gNB_Tx_8	3.781724
gNB_Tx_16	6.640729
gNB_Tx_32	10.288782
gNB_Tx_64	14.831004
gNB_Tx_128	19.321316

d. The 5G_Parameter_Log files will be present in the log folder present in the folder where the configuration.netsim and metrics.xml files are stored

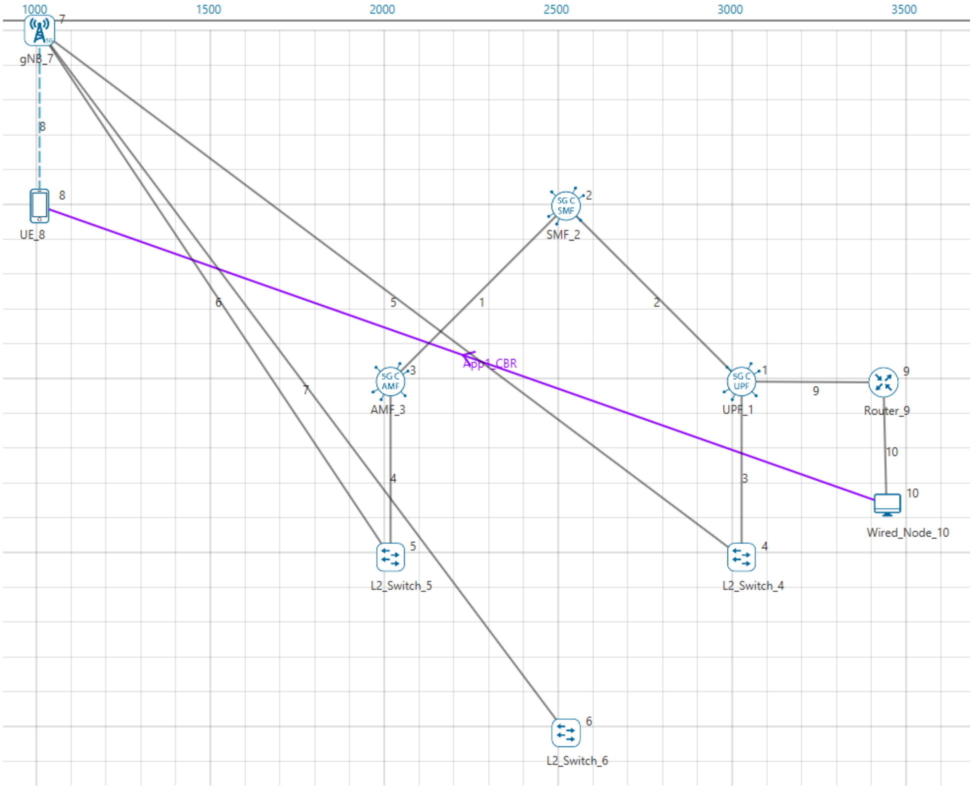


« Examples › Experiment-2 › MISO › Multi-Parameter-Sweeper › Data › MISO_gNB_Tx_1 › log

Name	Date modified	Type	Size
5G_LTE_Parameter_Log.csv	30-06-2021 20:17	Microsoft Excel C...	2,121 KB
ospf.log	30-06-2021 20:17	LOG File	0 KB
ospf_hello.log	30-06-2021 20:17	LOG File	0 KB
USER_INPUT_LTE_NR_PLOTS.txt	30-06-2021 20:17	Text Document	2 KB

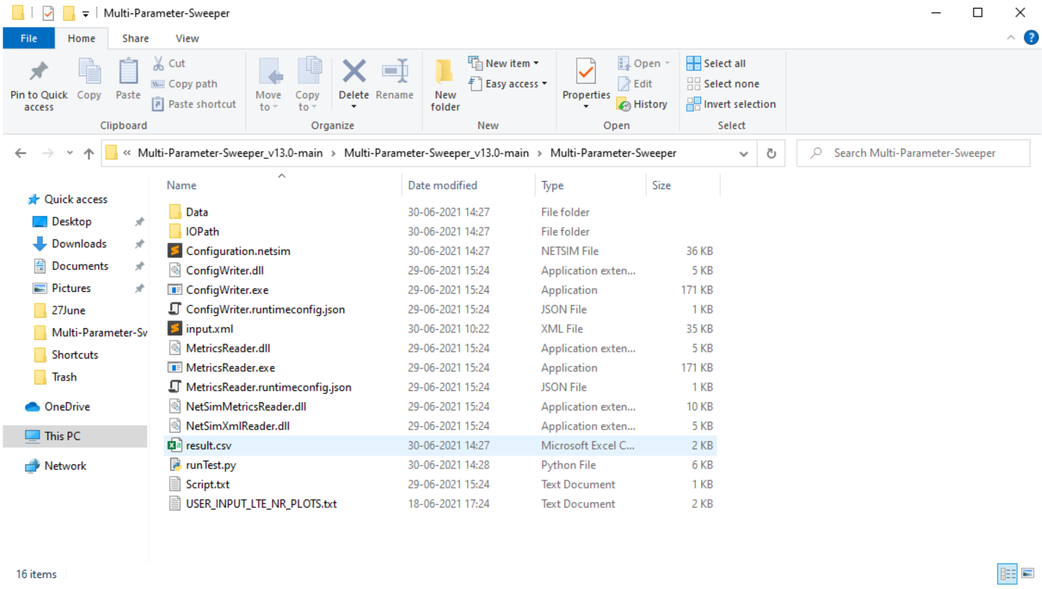
Experiment-4: Understanding 5G NR (3GPP) pathloss models

Consider the following network 5G network scenario in NetSim, comprising of a Wired Node, Router, gNB and a UE.



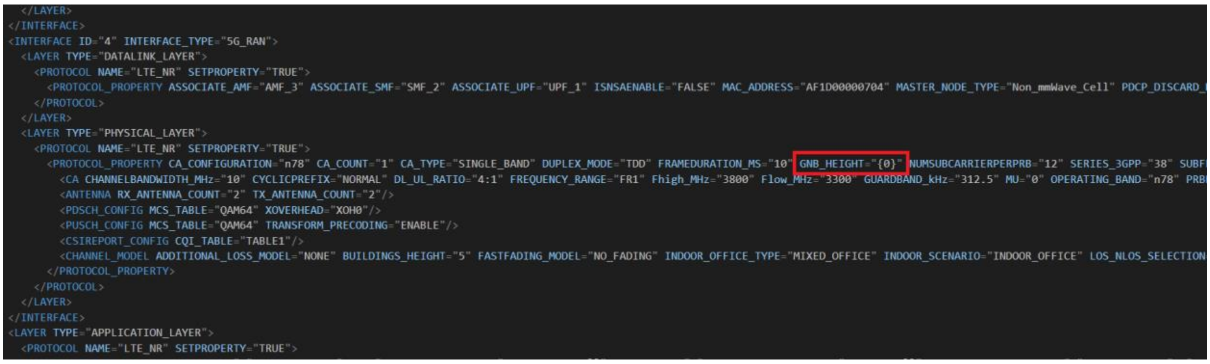
The network configuration has the initial distance between the gNB and UE as 50 meters with the gNB located at (1000,0) and UE located at (1000,50). Multi-Parameter Sweeper is configured to run simulations for different distance between the gNB and UE by varying the UE Y coordinate value from and also for different gNB Heights in both LOS and NLOS states.

6. The network scenario is saved and the content of the Configuration.netsim file is copied to the Multi-Parameter-Sweeper directory and renamed as input.xml. Refer to the Experiment 4 directory which is part of the project folder (Multi-ParameterSweeper_v13.0\Examples\Multi-Parameter-Sweeper-Experiment-4)



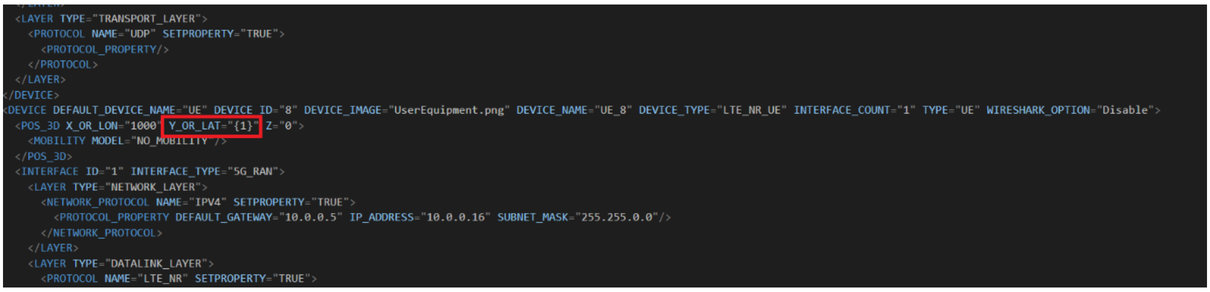
Name	Date modified	Type	Size
Data	30-06-2021 14:27	File folder	
IOPath	30-06-2021 14:27	File folder	
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ConfigWriter.dll	29-06-2021 15:24	Application exten...	5 KB
ConfigWriter.exe	29-06-2021 15:24	Application	171 KB
ConfigWriter.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
input.xml	30-06-2021 10:22	XML File	35 KB
MetricsReader.dll	29-06-2021 15:24	Application exten...	5 KB
MetricsReader.exe	29-06-2021 15:24	Application	171 KB
MetricsReader.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
NetSimMetricsReader.dll	29-06-2021 15:24	Application exten...	10 KB
NetSimXmlReader.dll	29-06-2021 15:24	Application exten...	5 KB
result.csv	30-06-2021 14:27	Microsoft Excel C...	2 KB
runTest.py	30-06-2021 14:28	Python File	6 KB
Script.txt	29-06-2021 15:24	Text Document	1 KB
USER_INPUT_LTE_NR_PLOTS.txt	18-06-2021 17:24	Text Document	2 KB

7. The value of the gNB Height of gNB that is to be modified during each simulation run is updated (“{0}”) in the configuration file as shown below:



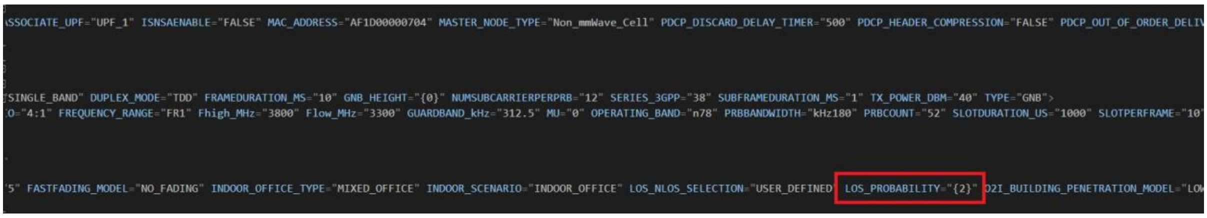
```
  </LAYER>
</INTERFACE>
<INTERFACE ID="4" INTERFACE_TYPE="5G_RAN">
  <LAYER TYPE="DATALINK_LAYER">
    <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
      <PROTOCOL_PROPERTY ASSOCIATE_AMF="AMF_3" ASSOCIATE_SMF="SMF_2" ASSOCIATE_UPF="UPF_1" ISNSAENABLE="FALSE" MAC_ADDRESS="AF1D00000704" MASTER_NODE_TYPE="Non_mmWave_Cell" PDCP_DISCARD_
    </PROTOCOL>
  </LAYER>
  <LAYER TYPE="PHYSICAL_LAYER">
    <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
      <PROTOCOL_PROPERTY CA_CONFIGURATION="n78" CA_COUNT="1" CA_TYPE="SINGLE_BAND" DUPLEX_MODE="TDD" FRAMEDURATION_MS="10" GNB_HEIGHT="{0}" NUMSUBCARRIERPERPRB="12" SERIES_3GPP="38" SUBF
        <CA CHANNELBANDWIDTH_MHz="10" CYCLICPREFIX="NORMAL" DL_UL_RATIO="4:1" FREQUENCY_RANGE="FR1" Fhigh_MHz="3800" Flow_MHz="3300" GUARDBAND_kHz="312.5" MU="0" OPERATING_BAND="n78" PRB
        <ANTENNA RX_ANTENNA_COUNT="2" TX_ANTENNA_COUNT="2"/>
        <PDSCH_CONFIG MCS_TABLE="QAM64" XOVERHEAD="XOH0"/>
        <PUSCH_CONFIG MCS_TABLE="QAM64" TRANSFORM_PRECODING="ENABLE"/>
        <CSIREPORT_CONFIG CQI_TABLE="TABLE1"/>
        <CHANNEL_MODEL ADDITIONAL_LOSS_MODEL="NONE" BUILDINGS_HEIGHT="5" FASTFADING_MODEL="NO_FADING" INDOOR_OFFICE_TYPE="MIXED_OFFICE" INDOOR_SCENARIO="INDOOR_OFFICE" LOS_NLOS_SELECTION
      </PROTOCOL_PROPERTY>
    </PROTOCOL>
  </LAYER>
</INTERFACE>
<LAYER TYPE="APPLICATION_LAYER">
  <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
```

8. The value of the Y Co-ordinate of UE that is to be modified during each simulation run is updated (“{1}”) in the configuration file as shown below:



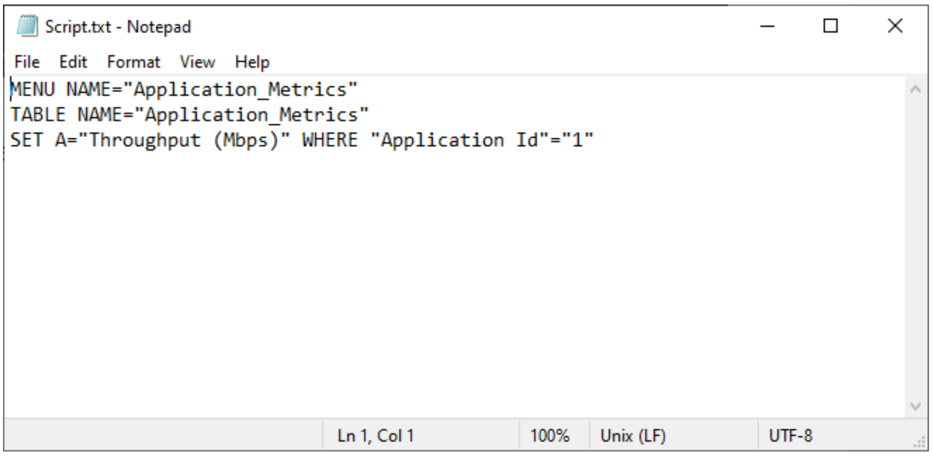
```
  <LAYER TYPE="TRANSPORT_LAYER">
    <PROTOCOL NAME="UDP" SETPROPERTY="TRUE">
      <PROTOCOL_PROPERTY/>
    </PROTOCOL>
  </LAYER>
</DEVICE>
<DEVICE DEFAULT_DEVICE_NAME="UE" DEVICE_ID="8" DEVICE_IMAGE="UserEquipment.png" DEVICE_NAME="UE_8" DEVICE_TYPE="LTE_NR_UE" INTERFACE_COUNT="1" TYPE="UE" WIRESHARK_OPTION="Disable">
  <POS_3D X_OR_LON="1000" Y_OR_LAT="{1}" Z="0">
    <MOBILITY MODEL="NO_MOBILITY"/>
  </POS_3D>
  <INTERFACE ID="1" INTERFACE_TYPE="5G_RAN">
    <LAYER TYPE="NETWORK_LAYER">
      <NETWORK_PROTOCOL NAME="IPV4" SETPROPERTY="TRUE">
        <PROTOCOL_PROPERTY DEFAULT_GATEWAY="10.0.0.5" IP_ADDRESS="10.0.0.16" SUBNET_MASK="255.255.0.0"/>
      </NETWORK_PROTOCOL>
    </LAYER>
    <LAYER TYPE="DATALINK_LAYER">
      <PROTOCOL NAME="LTE_NR" SETPROPERTY="TRUE">
```

9. The value of the LOS Probability of gNB that is to be modified during each simulation run is updated (“{2}”) in the configuration file as shown below:



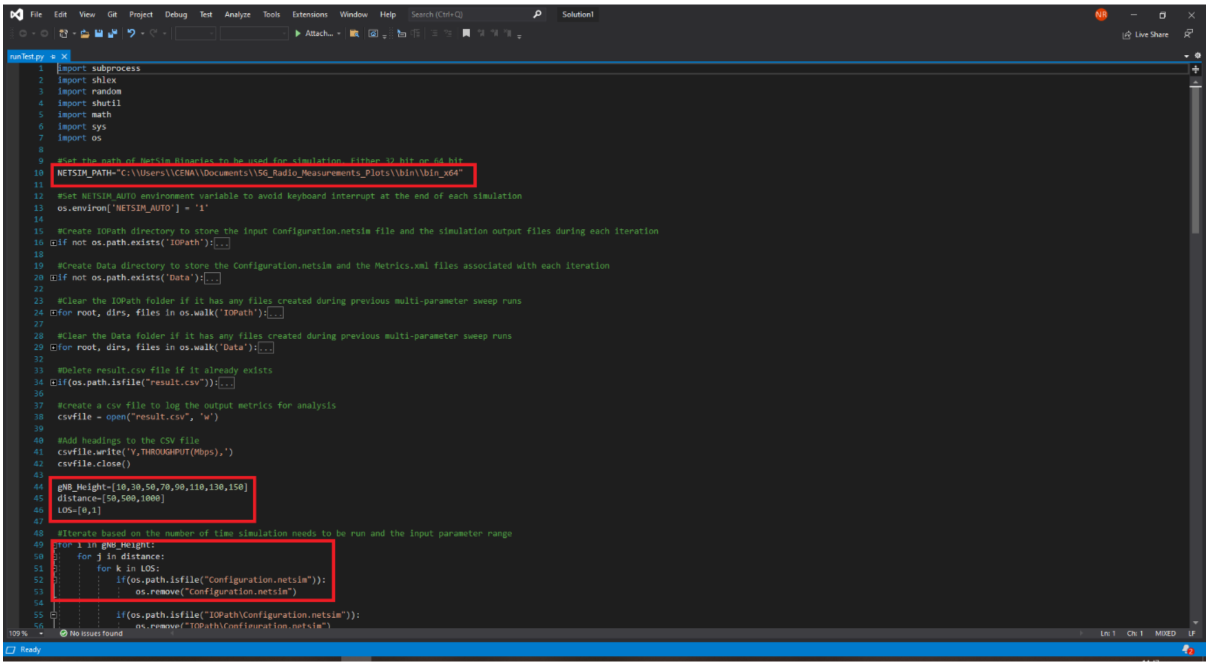
```
SSOCIATE_UPF="UPF_1" ISNSAENABLE="FALSE" MAC_ADDRESS="AF1D00000704" MASTER_NODE_TYPE="Non_mmWave_Cell" PDCP_DISCARD_DELAY_TIMER="500" PDCP_HEADER_COMPRESSION="FALSE" PDCP_OUT_OF_ORDER_DELIV



SINGLE_BAND" DUPLEX_MODE="TDD" FRAMEDURATION_MS="10" GNB_HEIGHT="{0}" NUMSUBCARRIERPERPRB="12" SERIES_3GPP="38" SUBFRAMEDURATION_MS="1" TX_POWER_DBM="40" TYPE="GNB">
O="4:1" FREQUENCY_RANGE="FR1" Fhigh_MHz="3800" Flow_MHz="3300" GUARDBAND_kHz="312.5" MU="0" OPERATING_BAND="n78" PRBBANDWIDTH="kHz180" PRBCOUNT="52" SLOTDURATION_US="1000" SLOTPERFRAME="10"



5" FASTFADING_MODEL="NO_FADING" INDOOR_OFFICE_TYPE="MIXED_OFFICE" INDOOR_SCENARIO="INDOOR_OFFICE" LOS_NLOS_SELECTION="USER_DEFINED" LOS_PROBABILITY="{2}" O2I_BUILDING_PENETRATION_MODEL="LOW
```

10. The Script.txt file is updated with the details of the output parameter to be read from the Metrics.xml file and added to the result csv log file. In this case the Application throughput is to be logged for each simulation run



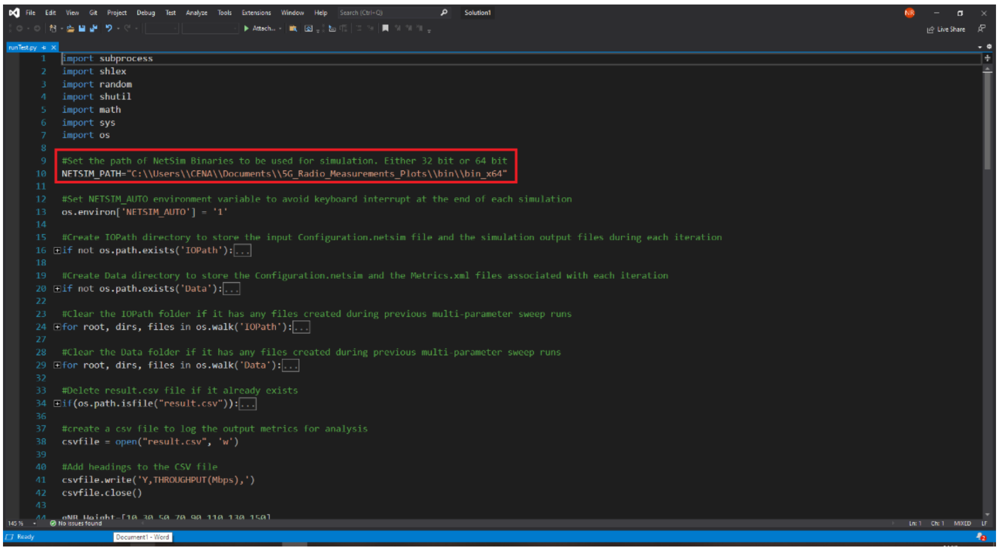
```
MENU NAME="Application_Metrics"
TABLE NAME="Application_Metrics"
SET A="Throughput (Mbps)" WHERE "Application Id"="1"
```

11. runTest.py is updated to pass the gNB Height, Y coordinate and LOS Probability value during each iteration to generate Configuration file run simulation and update the result csv log.



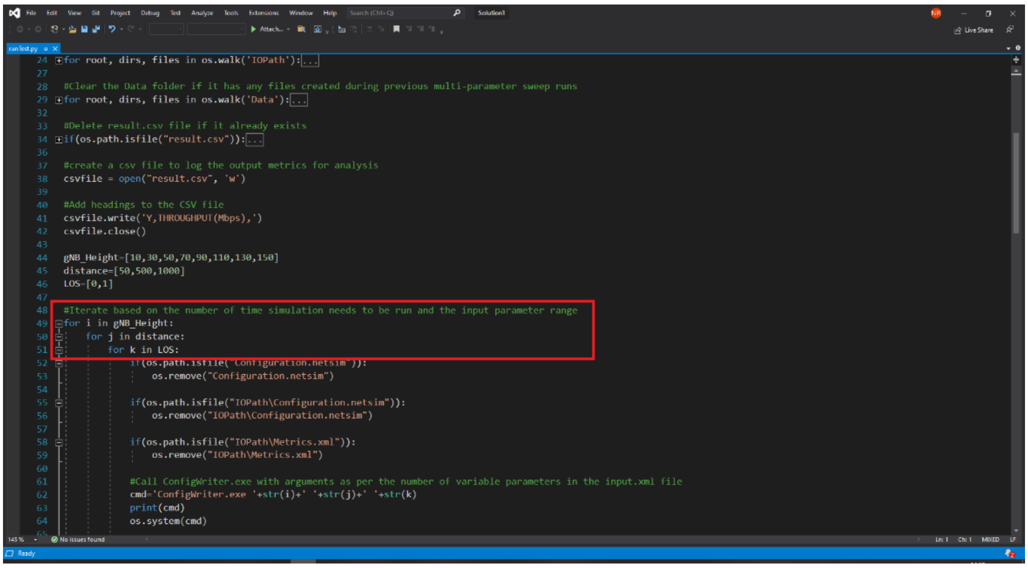
```
import subprocess
import shlex
import random
import shutil
import math
import sys
import os

#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Height=[10,30,50,70,90,110,130,150]
distance=[50,500,1000]
LOS=[0,1]

#Iterate based on the number of time simulation needs to be run and the input parameter range
for i in gNB_Height:
    for j in distance:
        for k in LOS:
            if(os.path.isfile("Configuration.netsim")):
                os.remove("Configuration.netsim")

            if(os.path.isfile("IOPath\Configuration.netsim")):
                os.remove("IOPath\Configuration.netsim")
```

- NETSIM_PATH variable is set to the path of NetSim 32-bit/64-bit binaries in the install directory or workspace in the system.



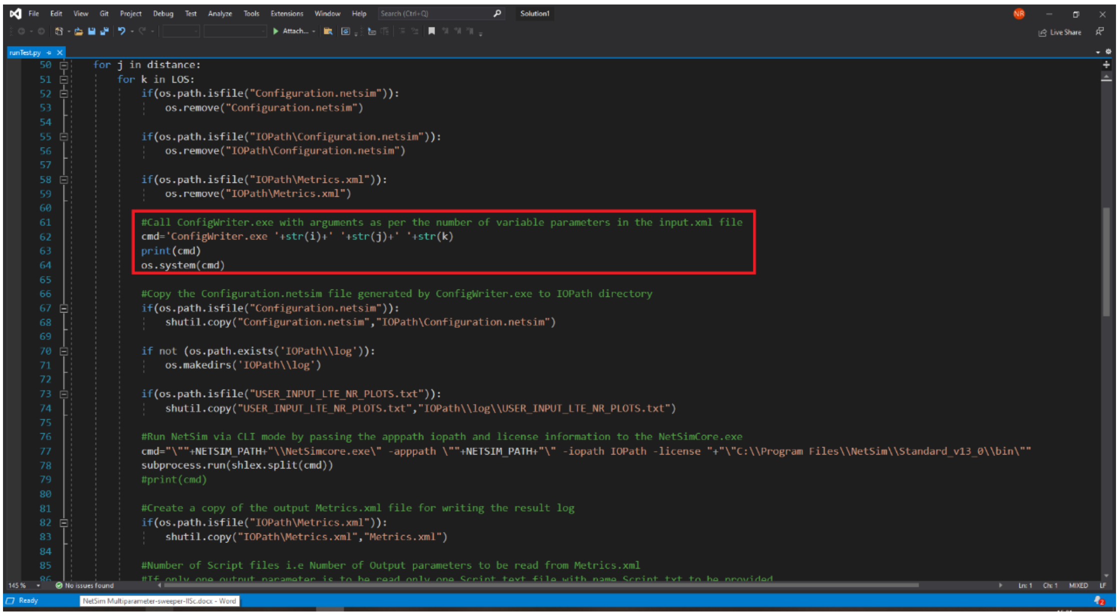
```python
import subprocess
import shlex
import random
import shutil
import math
import sys
import os

#Set the path of NetSim Binaries to be used for simulation. Either 32 bit or 64 bit
NETSIM_PATH="C:\\Users\\CENA\\Documents\\5G_Radio_Measurements_Plots\\bin\\bin_x64"

#Set NETSIM_AUTO environment variable to avoid keyboard interrupt at the end of each simulation
os.environ['NETSIM_AUTO'] = '1'

#Create IOPath directory to store the input Configuration.netsim file and the simulation output files during each iteration
if not os.path.exists('IOPath'):...

#Create Data directory to store the Configuration.netsim and the Metrics.xml files associated with each iteration
if not os.path.exists('Data'):...

#Clear the IOPath folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Height=[10,30,50,70,90,110,130,150]
```

- A result.csv file is created and added with headings Y and Throughput(Mbps)
- For loop is set to iteratively run simulations for values of gNB Height starting from 10 to 150 in steps of 20, distance values 50m, 500m and 1km and LOS Probability 0 and 1.



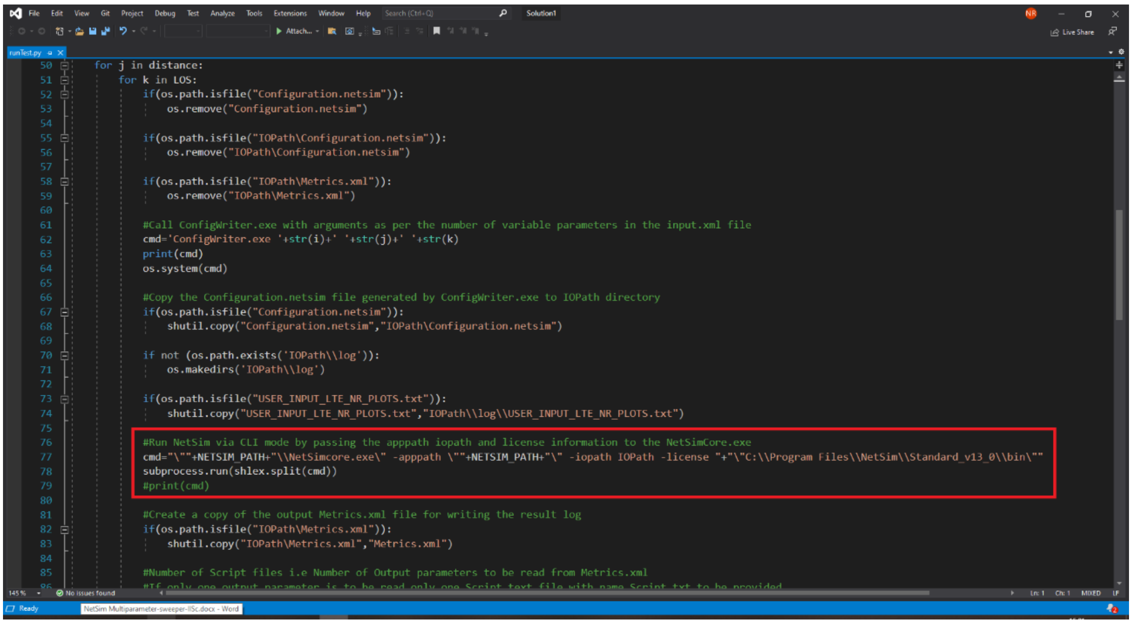
```python
for root, dirs, files in os.walk('IOPath'):...

#Clear the Data folder if it has any files created during previous multi-parameter sweep runs
for root, dirs, files in os.walk('Data'):...

#Delete result.csv file if it already exists
if(os.path.isfile("result.csv")):...

#create a csv file to log the output metrics for analysis
csvfile = open("result.csv", 'w')

#Add headings to the CSV file
csvfile.write('Y,THROUGHPUT(Mbps),')
csvfile.close()

gNB_Height=[10,30,50,70,90,110,130,150]
distance=[50,500,1000]
LOS=[0,1]

#Iterate based on the number of time simulation needs to be run and the input parameter range
for i in gNB_Height:
    for j in distance:
        for k in LOS:
            if(os.path.isfile("Configuration.netsim")):
                os.remove("Configuration.netsim")

            if(os.path.isfile("IOPath\Configuration.netsim")):
                os.remove("IOPath\Configuration.netsim")

            if(os.path.isfile("IOPath\Metrics.xml")):
                os.remove("IOPath\Metrics.xml")

            #Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
            cmd='ConfigWriter.exe '+str(i)+' '+str(j)+' '+str(k)
            print(cmd)
            os.system(cmd)
```

- The value of the parameters gNB Height, distance and LOS Probability in the current iteration is written to the result log file for analysis.
- The value of the parameters in the current iteration is passed as input to ConfigWriter executable to generate Configuration.netsim file for each simulation.



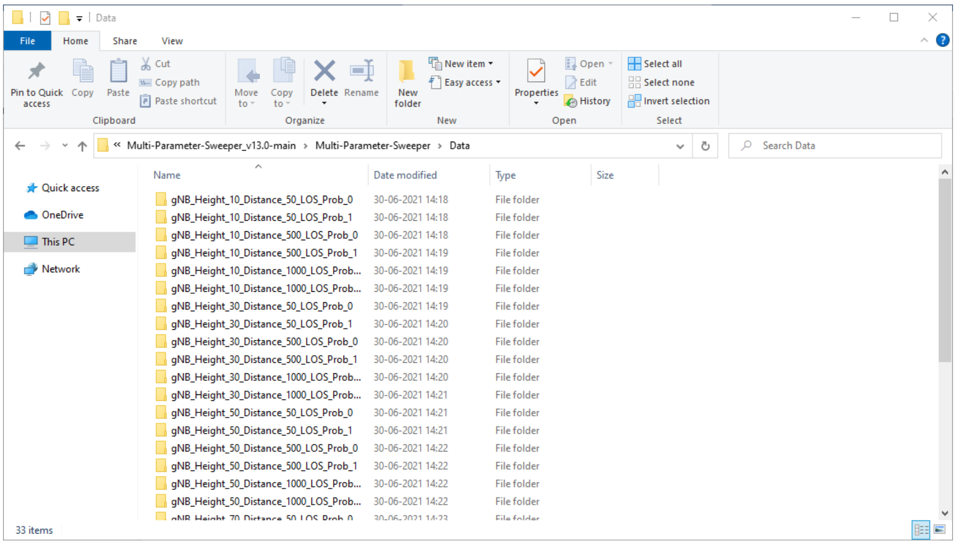
```
    for j in distance:
        for k in LOS:
            if(os.path.isfile("Configuration.netsim")):
                os.remove("Configuration.netsim")

            if(os.path.isfile("IOPath\Configuration.netsim")):
                os.remove("IOPath\Configuration.netsim")

            if(os.path.isfile("IOPath\Metrics.xml")):
                os.remove("IOPath\Metrics.xml")

            #Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
            cmd='ConfigWriter.exe '+str(i)+' '+str(j)+' '+str(k)
            print(cmd)
            os.system(cmd)

            #Copy the Configuration.netsim file generated by ConfigWriter.exe to IOPath directory
            if(os.path.isfile("Configuration.netsim")):
                shutil.copy("Configuration.netsim","IOPath\Configuration.netsim")

            if not (os.path.exists('IOPath\\log')):
                os.makedirs('IOPath\\log')

            if(os.path.isfile("USER_INPUT_LTE_NR_PLOTS.txt")):
                shutil.copy("USER_INPUT_LTE_NR_PLOTS.txt","IOPath\\log\\USER_INPUT_LTE_NR_PLOTS.txt")

            #Run NetSim via CLI mode by passing the apppath iopath and license information to the NetSimCore.exe
            cmd="\""+NETSIM_PATH+"\\NetSimcore.exe\" -apppath \""+NETSIM_PATH+"\" -iopath IOPath -license "+"\"C:\\Program Files\\NetSim\\Standard_v13_0\\bin\""
            subprocess.run(shlex.split(cmd))
            #print(cmd)

            #Create a copy of the output Metrics.xml file for writing the result log
            if(os.path.isfile("IOPath\Metrics.xml")):
                shutil.copy("IOPath\Metrics.xml","Metrics.xml")

            #Number of Script files i.e Number of Output parameters to be read from Metrics.xml
            #If only one output parameter is to be read only one Script text file with name Script.txt to be provided
```

- NetSim simulation is run via CLI mode by passing the apppath, iopath and license server information.



```
    for j in distance:
        for k in LOS:
            if(os.path.isfile("Configuration.netsim")):
                os.remove("Configuration.netsim")

            if(os.path.isfile("IOPath\Configuration.netsim")):
                os.remove("IOPath\Configuration.netsim")

            if(os.path.isfile("IOPath\Metrics.xml")):
                os.remove("IOPath\Metrics.xml")

            #Call ConfigWriter.exe with arguments as per the number of variable parameters in the input.xml file
            cmd='ConfigWriter.exe '+str(i)+' '+str(j)+' '+str(k)
            print(cmd)
            os.system(cmd)

            #Copy the Configuration.netsim file generated by ConfigWriter.exe to IOPath directory
            if(os.path.isfile("Configuration.netsim")):
                shutil.copy("Configuration.netsim","IOPath\Configuration.netsim")

            if not (os.path.exists('IOPath\\log')):
                os.makedirs('IOPath\\log')

            if(os.path.isfile("USER_INPUT_LTE_NR_PLOTS.txt")):
                shutil.copy("USER_INPUT_LTE_NR_PLOTS.txt","IOPath\\log\\USER_INPUT_LTE_NR_PLOTS.txt")

            #Run NetSim via CLI mode by passing the apppath iopath and license information to the NetSimCore.exe
            cmd="\""+NETSIM_PATH+"\\NetSimcore.exe\" -apppath \""+NETSIM_PATH+"\" -iopath IOPath -license "+"\"C:\\Program Files\\NetSim\\Standard_v13_0\\bin\""
            subprocess.run(shlex.split(cmd))
            #print(cmd)

            #Create a copy of the output Metrics.xml file for writing the result log
            if(os.path.isfile("IOPath\Metrics.xml")):
                shutil.copy("IOPath\Metrics.xml","Metrics.xml")

            #Number of Script files i.e Number of Output parameters to be read from Metrics.xml
            #If only one output parameter is to be read only one Script text file with name Script.txt to be provided
```

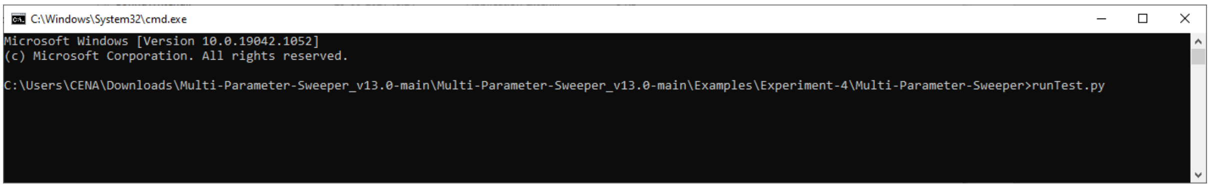
- Configuration file and Metrics file are copied and stored in folders appending the value of the parameter in the current iteration.



Name	Date modified	Type	Size
gNB_Height_10_Distance_50_LOS_Prob_0	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_50_LOS_Prob_1	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_500_LOS_Prob_0	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_500_LOS_Prob_1	30-06-2021 14:19	File folder	
gNB_Height_10_Distance_1000_LOS_Prob...	30-06-2021 14:19	File folder	
gNB_Height_10_Distance_1000_LOS_Prob...	30-06-2021 14:19	File folder	
gNB_Height_30_Distance_50_LOS_Prob_0	30-06-2021 14:19	File folder	
gNB_Height_30_Distance_50_LOS_Prob_1	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_500_LOS_Prob_0	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_500_LOS_Prob_1	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_1000_LOS_Prob...	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_1000_LOS_Prob...	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_50_LOS_Prob_0	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_50_LOS_Prob_1	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_500_LOS_Prob_0	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_500_LOS_Prob_1	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_1000_LOS_Prob...	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_1000_LOS_Prob...	30-06-2021 14:22	File folder	
gNB_Height_70_Distance_50_LOS_Prob_0	30-06-2021 14:23	File folder	

12. Multi-Parameter Sweeping process is started by opening command prompt in the directory of the Multi-Parameter-Sweeping project and starting the batch script or the python script as shown below:

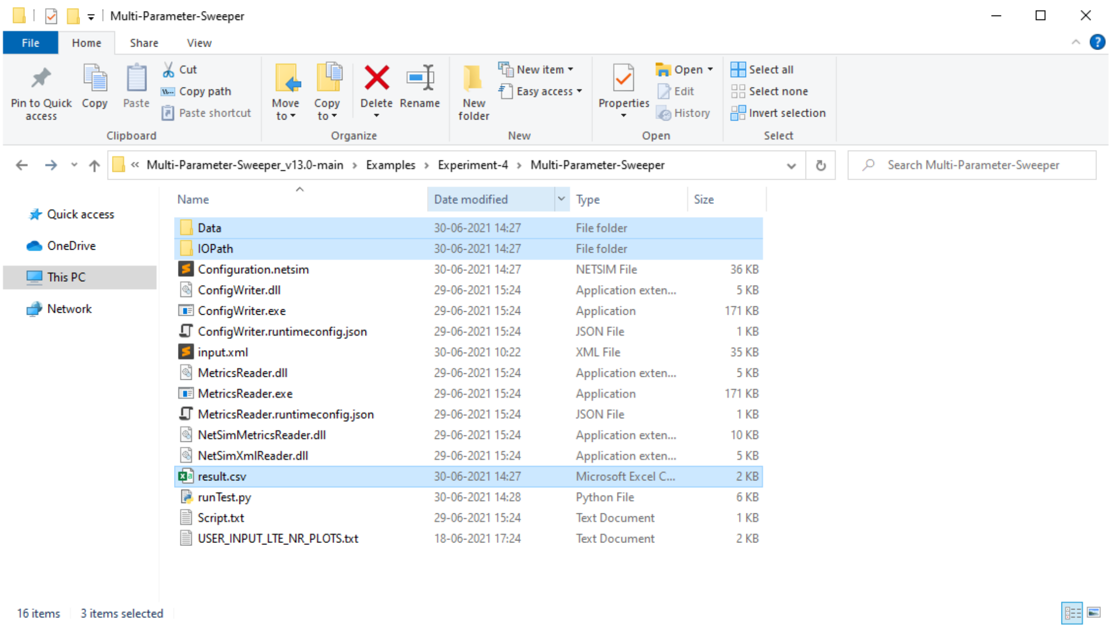
Python Script:



```
C:\Windows\System32\cmd.exe
Microsoft Windows [Version 10.0.19042.1052]
(c) Microsoft Corporation. All rights reserved.

C:\Users\CENA\Downloads\Multi-Parameter-Sweeper_v13.0-main\Multi-Parameter-Sweeper_v13.0-main\Examples\Experiment-4\Multi-Parameter-Sweeper>runTest.py
```

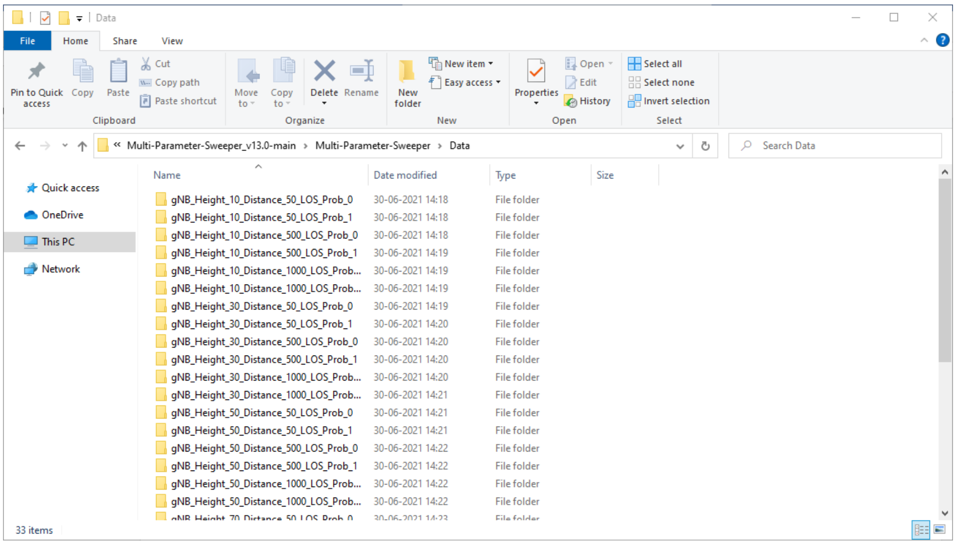
This starts the Multi-Parameter-Sweeping process which runs NetSim simulations iteratively for different values of parameters configured. The USER_INPUT_LTE_NR_PLOTS.txt file used as input is placed in the Multiparameter sweep directory.

At the end of the process the Multi-Parameter-Sweeping folder will have the following file and folders created:



Name	Date modified	Type	Size
Data	30-06-2021 14:27	File folder	
IOPath	30-06-2021 14:27	File folder	
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ConfigWriter.dll	29-06-2021 15:24	Application exten...	5 KB
ConfigWriter.exe	29-06-2021 15:24	Application	171 KB
ConfigWriter.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
input.xml	30-06-2021 10:22	XML File	35 KB
MetricsReader.dll	29-06-2021 15:24	Application exten...	5 KB
MetricsReader.exe	29-06-2021 15:24	Application	171 KB
MetricsReader.runtimeconfig.json	29-06-2021 15:24	JSON File	1 KB
NetSimMetricsReader.dll	29-06-2021 15:24	Application exten...	10 KB
NetSimXmlReader.dll	29-06-2021 15:24	Application exten...	5 KB
result.csv	30-06-2021 14:27	Microsoft Excel C...	2 KB
runTest.py	30-06-2021 14:28	Python File	6 KB
Script.txt	29-06-2021 15:24	Text Document	1 KB
USER_INPUT_LTE_NR_PLOTS.txt	18-06-2021 17:24	Text Document	2 KB

e. **Data:** The Data directory contains folders which contains the Configuration.netsim and the Metrics.xml files associated with each simulation run, including the value of the parameter in the folder name.

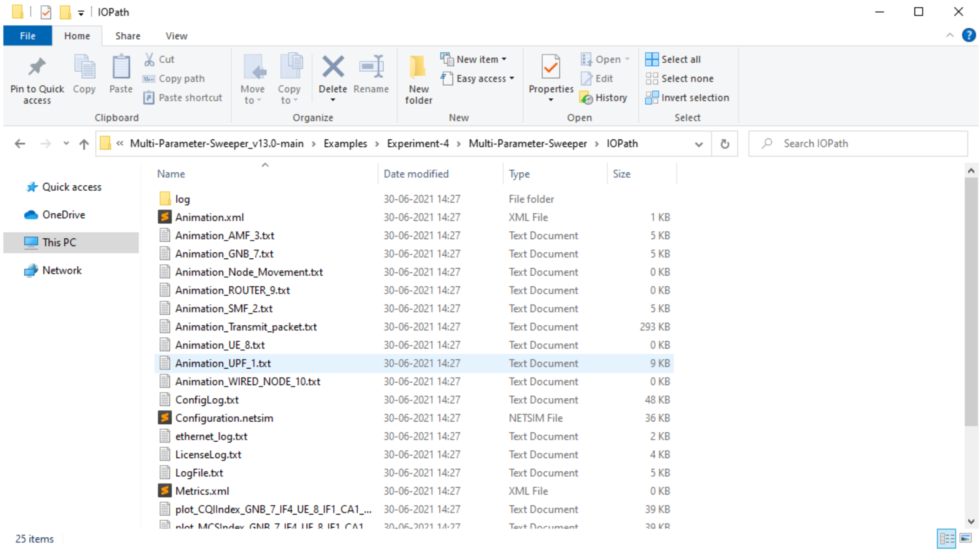


« Multi-Parameter-Sweeper_v13.0-main › Multi-Parameter-Sweeper › Data

Name	Date modified	Type	Size
gNB_Height_10_Distance_50_LOS_Prob_0	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_50_LOS_Prob_1	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_500_LOS_Prob_0	30-06-2021 14:18	File folder	
gNB_Height_10_Distance_500_LOS_Prob_1	30-06-2021 14:19	File folder	
gNB_Height_10_Distance_1000_LOS_Prob...	30-06-2021 14:19	File folder	
gNB_Height_10_Distance_1000_LOS_Prob...	30-06-2021 14:19	File folder	
gNB_Height_30_Distance_50_LOS_Prob_0	30-06-2021 14:19	File folder	
gNB_Height_30_Distance_50_LOS_Prob_1	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_500_LOS_Prob_0	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_500_LOS_Prob_1	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_1000_LOS_Prob...	30-06-2021 14:20	File folder	
gNB_Height_30_Distance_1000_LOS_Prob...	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_50_LOS_Prob_0	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_50_LOS_Prob_1	30-06-2021 14:21	File folder	
gNB_Height_50_Distance_500_LOS_Prob_0	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_500_LOS_Prob_1	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_1000_LOS_Prob...	30-06-2021 14:22	File folder	
gNB_Height_50_Distance_1000_LOS_Prob...	30-06-2021 14:22	File folder	
gNB_Height_70_Distance_50_LOS_Prob_0	30-06-2021 14:23	File folder	

33 items

f. **IOPath:** Used for storing the Configuration.netsim file and the simulation files generated during each simulation run.

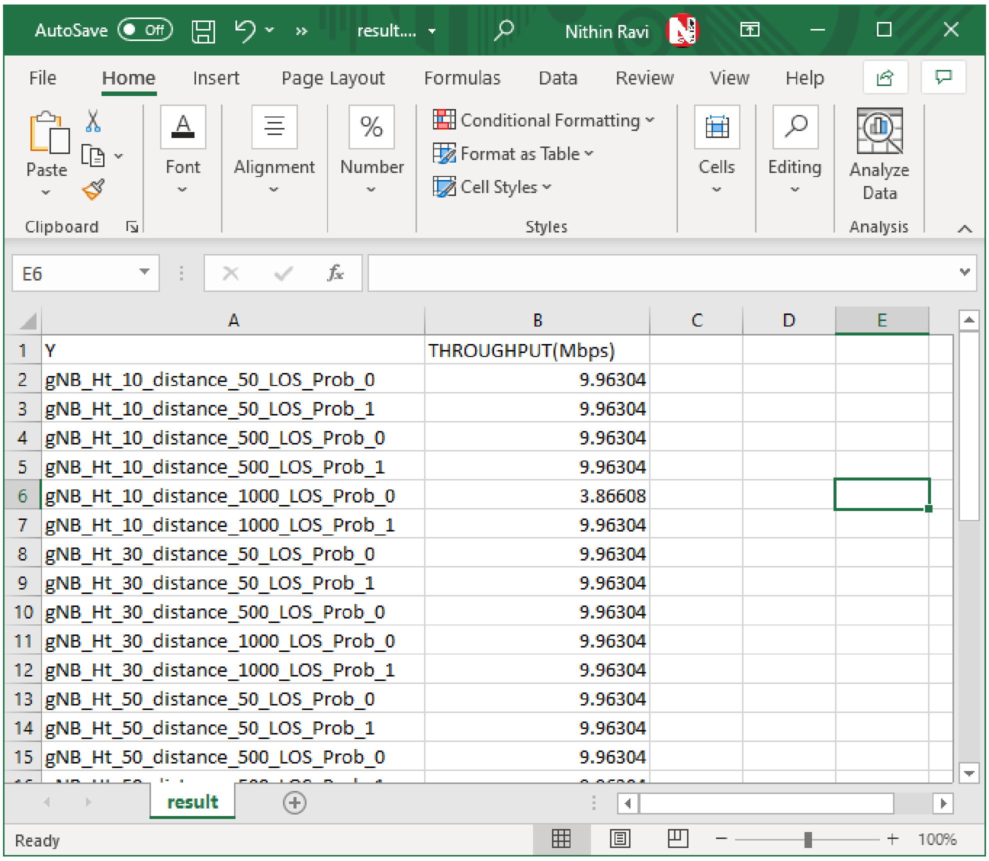


« Multi-Parameter-Sweeper_v13.0-main › Examples › Experiment-4 › Multi-Parameter-Sweeper › IOPath

Name	Date modified	Type	Size
log	30-06-2021 14:27	File folder	
Animation.xml	30-06-2021 14:27	XML File	1 KB
Animation_AMF_3.txt	30-06-2021 14:27	Text Document	5 KB
Animation_GNB_7.txt	30-06-2021 14:27	Text Document	5 KB
Animation_Node_Movement.txt	30-06-2021 14:27	Text Document	0 KB
Animation_ROUTER_9.txt	30-06-2021 14:27	Text Document	0 KB
Animation_SMF_2.txt	30-06-2021 14:27	Text Document	5 KB
Animation_Transmit_packet.txt	30-06-2021 14:27	Text Document	293 KB
Animation_UE_8.txt	30-06-2021 14:27	Text Document	0 KB
Animation_UPF_1.txt	30-06-2021 14:27	Text Document	9 KB
Animation_WIRED_NODE_10.txt	30-06-2021 14:27	Text Document	0 KB
ConfigLog.txt	30-06-2021 14:27	Text Document	48 KB
Configuration.netsim	30-06-2021 14:27	NETSIM File	36 KB
ethernet_log.txt	30-06-2021 14:27	Text Document	2 KB
LicenseLog.txt	30-06-2021 14:27	Text Document	4 KB
LogFile.txt	30-06-2021 14:27	Text Document	5 KB
Metrics.xml	30-06-2021 14:27	XML File	0 KB
plot_CQIIndex_GNB_7_IF4_UE_8_IF1_CA1_...	30-06-2021 14:27	Text Document	39 KB
plot_MCSIndex_GNB_7_IF4_UE_8_IF1_CA1	30-06-2021 14:27	Text Document	39 KB

25 items

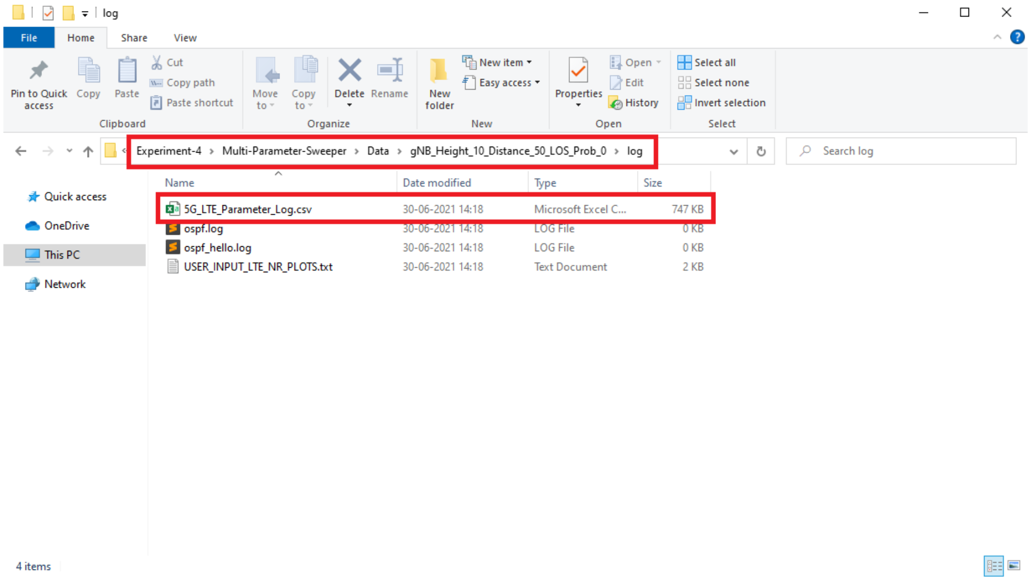
g. **Result.csv:** This is the output log which contains the parameter varied during each simulation run and the output parameter associated with each run.



E6

	A	B	C	D	E
1	Y	THROUGHPUT(Mbps)			
2	gNB_Ht_10_distance_50_LOS_Prob_0	9.96304			
3	gNB_Ht_10_distance_50_LOS_Prob_1	9.96304			
4	gNB_Ht_10_distance_500_LOS_Prob_0	9.96304			
5	gNB_Ht_10_distance_500_LOS_Prob_1	9.96304			
6	gNB_Ht_10_distance_1000_LOS_Prob_0	3.86608			
7	gNB_Ht_10_distance_1000_LOS_Prob_1	9.96304			
8	gNB_Ht_30_distance_50_LOS_Prob_0	9.96304			
9	gNB_Ht_30_distance_50_LOS_Prob_1	9.96304			
10	gNB_Ht_30_distance_500_LOS_Prob_0	9.96304			
11	gNB_Ht_30_distance_1000_LOS_Prob_0	9.96304			
12	gNB_Ht_30_distance_1000_LOS_Prob_1	9.96304			
13	gNB_Ht_50_distance_50_LOS_Prob_0	9.96304			
14	gNB_Ht_50_distance_50_LOS_Prob_1	9.96304			
15	gNB_Ht_50_distance_500_LOS_Prob_0	9.96304			

h. The 5G_Parameter_Log files will be present in the log folder present in the folder where the configuration.netsim and metrics.xml files are stored



Experiment-4 › Multi-Parameter-Sweeper › Data › gNB_Height_10_Distance_50_LOS_Prob_0 › log

Name	Date modified	Type	Size
5G_LTE_Parameter_Log.csv	30-06-2021 14:18	Microsoft Excel C...	747 KB
ospf.log	30-06-2021 14:18	LOG File	0 KB
ospf_hello.log	30-06-2021 14:18	LOG File	0 KB
USER_INPUT_LTE_NR_PLOTS.txt	30-06-2021 14:18	Text Document	2 KB