A Simulation of an LTE Network using NS3

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ABSTRACT

The aim of this project is to simulate an LTE network using the NS3 software. A basic LTE network is composed of a number of cells, wherein each cell has a base station node (eNodeB) and many User Equipment (UE) nodes. The simulation then proceeds to show us how two UE nodes communicate with each other, as well as with a base station node or an eNodeB. A simulation of the uplink communication shows us how the UE nodes send messages/information to the base station, while a simulation of the downlink communication illustrates how the base stations transmit information to the corresponding UE nodes that fall under their jurisdiction. The project also simulates a handover scenario wherein if a UE node happens to get a stronger signal from a base station other than the one by which it was being served previously, then it successfully gets 'handed over' to the base station from which it is receiving a stronger signal at present.

MOTIVATION BEHIND DOING THE PROJECT

The Long Term Evolution (LTE) wireless communication standard was developed by the 3rd Generation Partnership Project (3GPP) to provide 10 times the speeds of that of the 3G networks. This is the main motivation behind simulating an LTE network which is capable of performing voice and data communications at such high speeds. In simulating the LTE network, we make use of an EPC helper (Evolved Packet Core) apart from the conventional LTE helper since it is possible to transmit both data and voice by using the EPC protocol in the LTE network.

EXPLANATION OF THE PROJECT:

1) **Setting up of a basic LTE Network:**
    - The first step in setting up a basic LTE network is to create a number of node objects and then provide them with the methods to add eNodeBs and UEs before finally configuring them.
    - Now that we have configured a set of nodes as eNodeBs and another set of nodes as UEs, we proceed to install an LTE protocol stack on top of them, as they are just empty nodes as of now. We then proceed to configure the mobility model for all the nodes.
    - The positions of the nodes can be set by using the 'SetPositionAllocator' function of the mobility module. Hardcoding the positions of all the nodes can be a tedious task since we have many nodes in our case. Hence, we assigned locations to the nodes in such a way that they formed a grid inside the cell by declaring the number of required rows and columns in the grid, and by declaring the gap between any two consecutive nodes.
    - The next step is to attach all the UE nodes to one of the eNodeBs. In this way, we can configure each UE node in line with the configuration of the eNodeB. Consequently, a Radio Resource Control (RRC) connection is established between each UE node and its corresponding eNodeB. This means that we have all are channels firmly in place so that we can start the required communications between the UEs and the eNodeBs.

2) **Illustration of traffic within the LTE network:**

    - In case we want to know in which region of the LTE network there exists the maximum amount of traffic, we can do so by activating a data radio bearer between each UE and the eNodeB it is connected to.
    - The activation of the data radio bearers achieves the task of activating two saturation traffic generators for any given bearer, one in case of the uplink communication and the other in case of downlink communication.

- As far as our simulation is concerned, we can observe the generated traffic due to the communication between the UEs and the eNodeBs in the form of a set of concentric circles. The higher the density of concentric circles in a given region, the higher is the traffic in that particular region.

3) Simulation of a handover scenario:

- To simulate a handover scenario wherein one of the UE nodes which was previously connected to an eNodeB but has now been handed over to another eNodeB from which it might be receiving a higher signal strength, we have two primary tasks to perform:

  (i) To get notified about the establishment of a connection between the UE node and the eNodeB;

  (ii) At the two instants when the handover of a UE node starts and at When the handover ends, we need to get notified.

- We perform these two tasks by writing three functions: one for noting down the establishment of a connection between a UE node and an eNodeB along with the time instant at which the connection got established; and another two functions for notifying us of the commencement and ending of the handover process respectively.
- The handover starts when the UE node starts receiving signals of better signal strength from an eNodeB other than the one by which it was being served. The handover takes a miniscule amount of time to successfully get completed and after the handover takes place, the UE node has now successfully established a connection with the new eNodeB.

4) Testing the robustness of the simulated LTE network:

- The very purpose of simulating a new network standard altogether like the LTE is to make considerably large improvements over the older standards not only in terms of speeds, but in terms of several other evaluation criteria. The evaluation criteria are enumerated as follows:

1. **Delay (end-to-end mean delay):** The end-to-end delay needs to be reduced as much as possible. The greater the reduction in end-to-end delay when compared to the older standards, the more robust our LTE network is.
2. **Throughput:** The network throughput is the rate of successful message delivery over a communication channel. Our network throughput needs to be maximised for us to have a good network.
3. **Packet loss ratio:** The lower the ratio of the number of packets lost to the total number of packets transmitted, the better.

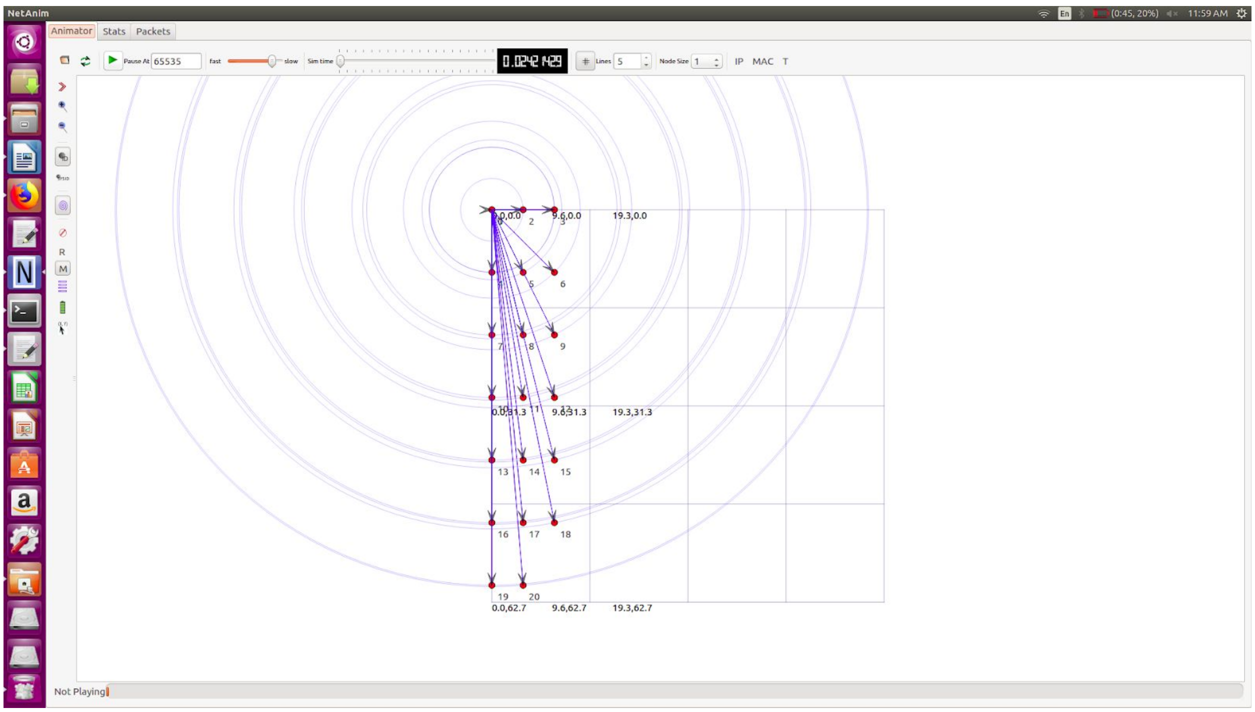
The other evaluation criteria of our network that are computed by virtue of the flow monitor package of NS3 are mean Jitter, mean transmitted packet size (in bytes), mean received packet size (in bytes), mean transmitted bitrate (bit/s), mean received bitrate (in bit/s), mean hop count and the number of lost packets.

All the aforementioned evaluation criteria corresponding to any given network can be computed by using the flow-monitor package of NS3. In our case, we install a single flow-monitor over all the nodes present in the network so that all the evaluation criteria can be consequently computed.

In this way, we can test the robustness of the LTE network that we have simulated.

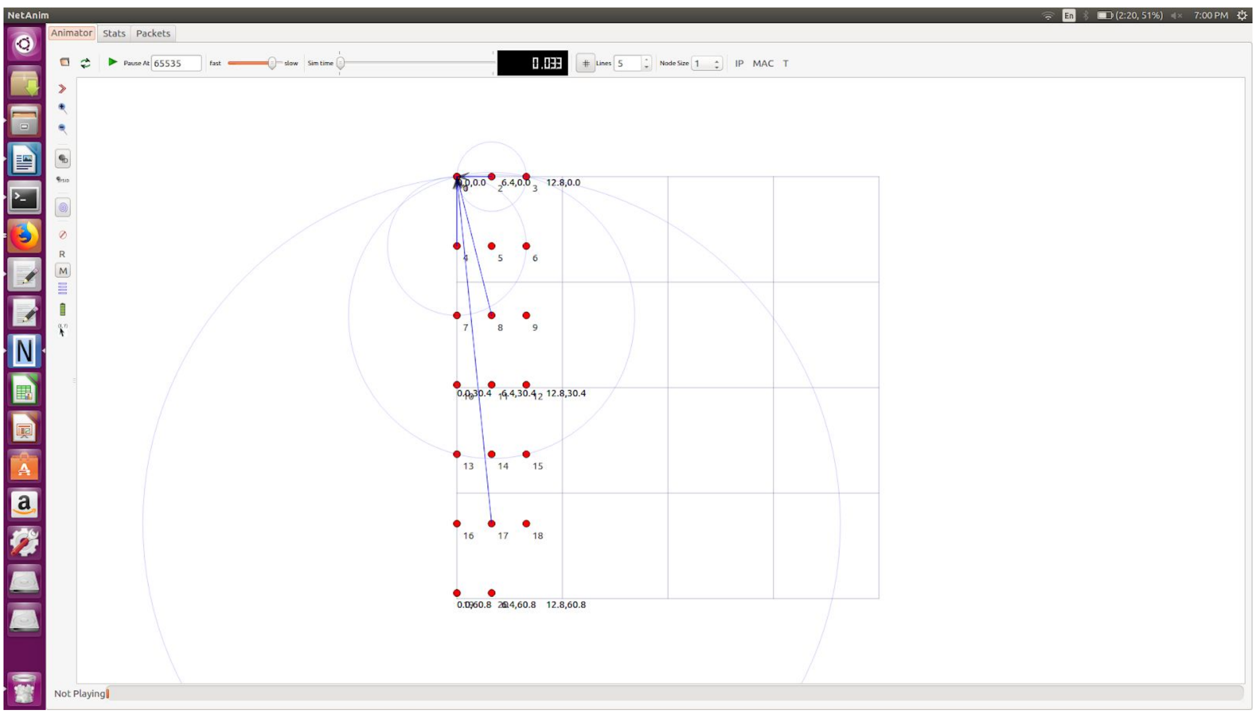
RESULTS

I. DOWNLINK COMMUNICATION:



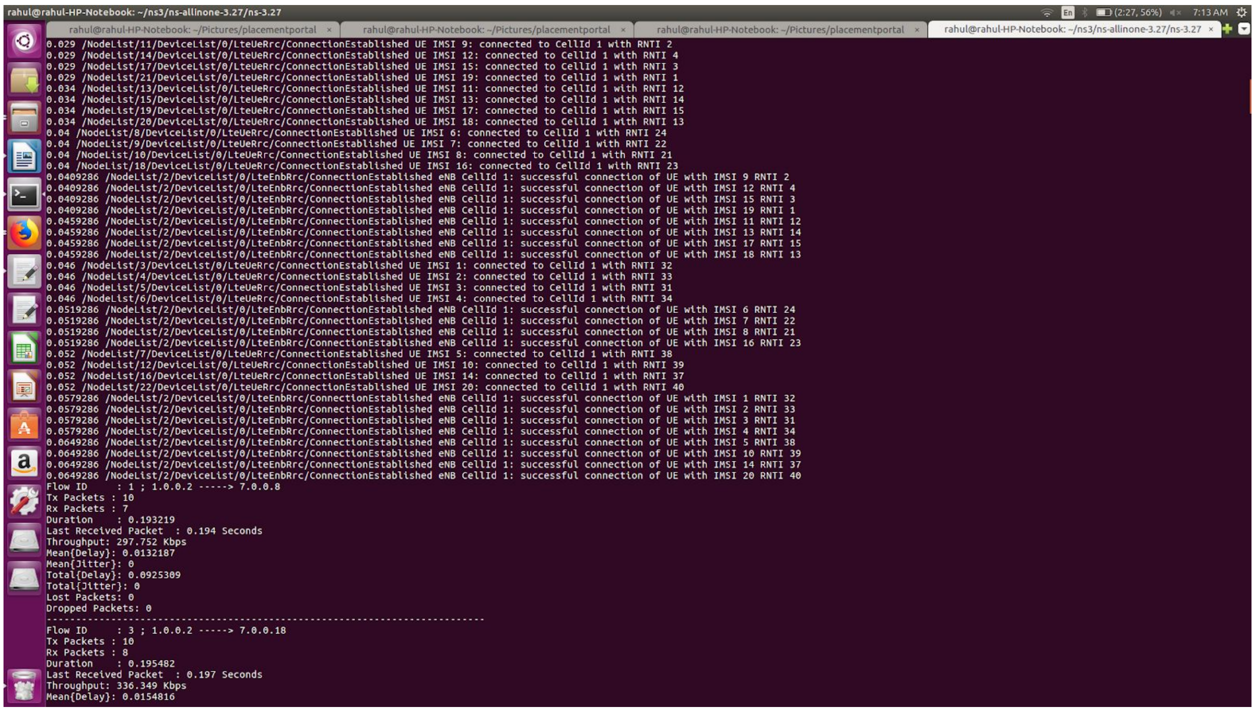
The above figure illustrates the downlink communication of the LTE network wherein the base station sends messages/information to all its corresponding UE nodes. The arrow marks pointing down indicate the direction of transmission of the messages which confirms that this is a case of downlink communication. The traffic density in a given region can be observed by virtue of the concentric circles, which we obtained by activating the data radio bearers.

II. UPLINK COMMUNICATION



The above figure illustrates the uplink communication of the LTE network wherein the UE nodes send messages/information to their corresponding base station. The arrow marks pointing upwards in the direction of the base station indicate the direction of transmission of the messages which confirms that this is a case of uplink communication. The traffic density in a given region can be observed by virtue of the concentric circles, which we obtained by activating the data radio bearers.

III. HANDOVER SCENARIO:

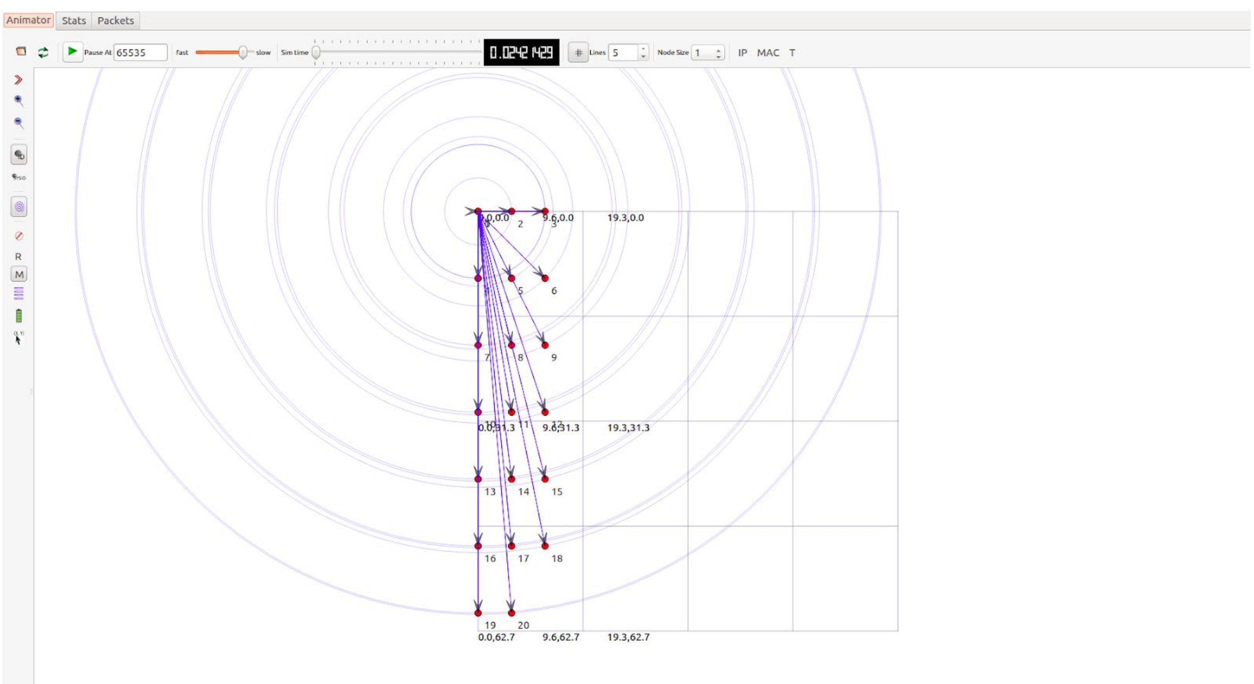


The simulation of the handover scenario begins with the establishment of the connection of a UE (which is identified by its International Mobile Subscriber Identity, IMSI) with its corresponding eNodeB (identified by its Radio Network Temporary Identifier, RNTI). We print on the terminal the exact time instants at which the connection is established. Next, as soon as a mobile UE starts receiving a signal of a better signal strength from a base station other than the one to which it had connected until now, we see that the UE node gets handed over as follows:

```
rahul@rahul-HP-Notebook:~/ns3/ns-allinone-3.27/ns-3.27$ ./waf --run scratch/hand
Waf: Entering directory `/home/rahul/ns3/ns-allinone-3.27/ns-3.27/build'
Waf: Leaving directory `/home/rahul/ns3/ns-allinone-3.27/ns-3.27/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (12.863s)
/NodeList/4/DeviceList/0/LteUeRrc/ConnectionEstablished UE IMSI 1: connected to CellId 1 with RNTI 1
/NodeList/2/DeviceList/0/LteEnbRrc/ConnectionEstablished eNB CellId 1: successful connection of UE with IMSI 1 RNTI 1
/NodeList/2/DeviceList/0/LteEnbRrc/HandoverStart eNB CellId 1: start handover of UE with IMSI 1 RNTI 1 to CellId 2
/NodeList/4/DeviceList/0/LteUeRrc/HandoverStart UE IMSI 1: previously connected to CellId 1 with RNTI 1, doing handover to CellId 2
/NodeList/4/DeviceList/0/LteUeRrc/HandoverEndOk UE IMSI 1: successful handover to CellId 2 with RNTI 1
/NodeList/3/DeviceList/0/LteEnbRrc/HandoverEndOk eNB CellId 2: completed handover of UE with IMSI 1 RNTI 1
```

As we can see in the above result, at the beginning of time, the UE node with IMSI 1 was connected to a base station with a CellId of 1 and an RNTI of 1. In the third line of the results, we can clearly observe that due to the mobility of the UE node, the UE node gets handed over to the base station with a CellId of 2. We first get notified about the start of the handover scenario both from the UE and the eNodeB perspectives. As soon as the miniscule duration of the handover gets over, we get notified about the end of the handover and we get to see that the UE node has been successfully handed over from one base station to the other.

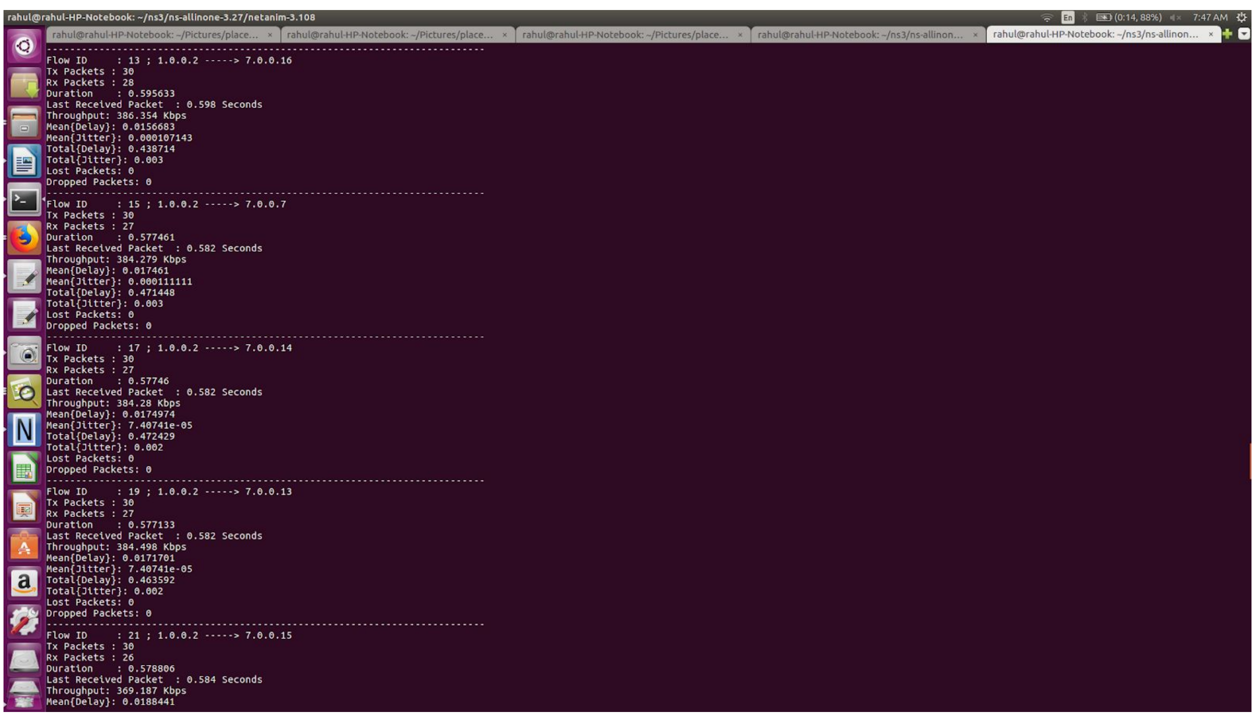
The animation of the handover scenario is as follows:



In the figure, we can observe that the UE nodes that were earlier performing the process of uplink communication with the base station with CellId 1 get successfully handed over to the base station with CellId 2. After the UE nodes get handed over, they continue to perform their functions of uplink and downlink communication as usual.

IV. COMPUTATION OF EVALUATION CRITERIA

The evaluation criteria of the simulation was evaluated using the flow-monitor package of NS3. The evaluation criteria corresponding to each flow was printed in the terminal. A flow is nothing but a single one-way transmission of voice or data packets from one node to the other (eNodeB or UE). in our case, each flow has been assigned with a flow ID so that we can distinguish between all the different flows that take place during the course of the simulation and so that they can be accordingly evaluated according to their corresponding evaluation criteria.



Attached above is a sample of 5 flows from the many flows that took place during the course of the simulation.

Let us look at have at single flow in detail:

```
Flow ID     : 15 ; 1.0.0.2 -----> 7.0.0.7
Tx Packets : 30
Rx Packets : 27
Duration    : 0.577461
Last Received Packet  : 0.582 Seconds
Throughput: 384.279 Kbps
Mean{Delay}: 0.017461
Mean{Jitter}: 0.000111111
Total{Delay}: 0.471448
Total{Jitter}: 0.003
Lost Packets: 0
Dropped Packets: 0
```

Here, the transmission of 30 packets is taking place from the eNodeB node with IP address 1.0.0.2 to the UE node with an IP address of 7.0.0.7. This transmission has a flow ID of 15. As far as the evaluation criteria is concerned, we can see that it takes just 0.577461 seconds for the eNodeB to transmit a total of 30 packets, while achieving a throughput of 384.279 Kbps. We can also see that we have considerably low values of mean delay and mean jitter. No packets are lost or dropped during the entirety of the flow, indicating the robustness of our network.

REFERENCES OF MATERIAL AND SOFTWARE USED:

1) **Software:** NS3 (version 3.27) and NetAnim (version 3.108)
2) **Material:**
    - LTE Module library on nsnam.org: https://www.nsnam.org/docs/models/html/lte.html
    - https://www.researchgate.net/publication/228998229_Handover_Scenario_and_Procedure_in_LTE-based_Femtocell_Networks