CIS549 – Project 5

DeSanctis/Finn/Jarčev/Schwyzer

Problem 1:

From the throughput chart, we can see that each UE obtains roughly equal throughput with total throughput being equal to the sum of all 3 UEs.

A screenshot of a social media post

Description automatically generated

From the download stats file, we can validate some of the entries:

time celId IMSI frame sfrm RNTI mcsTb size1 mcs2 sz2 Nprb

1.551 1 3 156 2 1 5 1095 0 0 98

1.624 1 2 163 5 3 25 7167 0 0 98

1.625 1 2 163 6 3 20 4904 0 0 98

1.626 1 2 163 7 3 20 4904 0 0 98

1.627 1 1 163 8 2 15 3542 0 0 97

1.628 1 1 163 9 2 15 3542 0 0 97

1.629 1 1 163 10 2 15 3542 0 0 97

1.63 1 1 164 1 2 10 1980 0 0 99

1.631 1 1 164 2 2 10 1980 0 0 99

For instance, we take the frame ID (minus 1 because the subframes start with 1 in the file, but in our program they start with 0) and add to the subframe (minus 1 because the subframes are listed as 1-10, but in our program, they are 0-9). So, Frame 163, subframe 10 is row 1629 in our validation sheet and Frame 164, subframe 1 is row 1630. For IMSI=1 (came from the UE2.txt parameter file), we can see the MCS value change from 15 to 10. Below is a subset of our validation spreadsheet. It shows that we can expect the MCS value to change from 15 to 10.

|  |  |  |  |
| --- | --- | --- | --- |
| frame | UE1(3) MCS | UE2(1) MCS | UE3(2) MCS |
| 1623 | 5 | 15 | 25 |
| 1624 | 1 | 10 | 20 |
| 1625 | 5 | 15 | 25 |
| 1626 | 1 | 10 | 20 |
| 1627 | 5 | 15 | 25 |
| 1628 | 1 | 10 | 20 |
| 1629 | 5 | 15 | 25 |
| 1630 | 1 | 10 | 20 |
| 1631 | 5 | 15 | 25 |
| 1632 | 1 | 10 | 20 |
| 1633 | 5 | 15 | 25 |

Let’s take another example for IMSI=3 (came from the UE1.txt parameter file):

time celId IMSI frame sfrm RNTI mcsTb size1 mcs2 sz2 Nprb

1.042 1 3 105 3 1 5 349 0 0 32

1.042 1 1 105 3 2 10 645 0 0 32

1.042 1 2 105 3 3 20 1572 0 0 32

1.139 1 1 114 10 2 10 645 0 0 32

1.139 1 2 114 10 3 20 1572 0 0 32

1.139 1 3 114 10 1 1 145 0 0 32

1.14 1 3 115 1 1 1 217 0 0 47

1.14 1 1 115 1 2 10 935 0 0 47

1.141 1 3 115 2 1 1 453 0 0 98

1.142 1 3 115 3 1 1 453 0 0 98

1.143 1 3 115 4 1 5 1095 0 0 98

1.236 1 2 124 7 3 20 4904 0 0 98

1.237 1 1 124 8 2 10 1980 0 0 99

1.238 1 1 124 9 2 10 1980 0 0 99

Here you can see Frame 115, subframe 3 (row 1142 in the validation sheet) and Frame 115, subframe 4 (row 1143). The MCS value changes from 5 to 1, which is what we see in the validation sheet:

|  |  |  |  |
| --- | --- | --- | --- |
| frame | UE1(3) MCS | UE2(1) MCS | UE3(2) MCS |
| 1138 | 1 | 10 | 20 |
| 1139 | 5 | 15 | 25 |
| 1140 | 1 | 10 | 20 |
| 1141 | 5 | 15 | 25 |
| 1142 | 1 | 10 | 20 |
| 1143 | 5 | 15 | 25 |
| 1144 | 1 | 10 | 20 |
| 1145 | 5 | 15 | 25 |
| 1146 | 1 | 10 | 20 |
| 1147 | 5 | 15 | 25 |
| 1148 | 1 | 10 | 20 |

Final example for IMSI=2 (came from the UE3.txt parameter file):

time celId IMSI frame sfrm RNTI mcsTb size1 mcs2 sz2 Nprb

3.963 1 2 397 4 3 20 2385 0 0 48

3.964 1 2 397 5 3 20 2385 0 0 48

3.964 1 3 397 5 1 5 533 0 0 48

3.965 1 2 397 6 3 20 2385 0 0 48

3.965 1 3 397 6 1 1 217 0 0 47

3.966 1 3 397 7 1 1 217 0 0 47

3.966 1 2 397 7 3 20 2385 0 0 48

3.967 1 2 397 8 3 25 3422 0 0 47

3.967 1 3 397 8 1 1 217 0 0 47

3.968 1 2 397 9 3 25 3422 0 0 47

Here you can see Frame 397, subframe 7 (row 3966 in the validation sheet) and Frame 397, subframe 8 (row 3967). The MCS value changes from 20 to 25, which is what we see in the validation sheet:

|  |  |  |  |
| --- | --- | --- | --- |
| frame | UE1(3) MCS | UE2(1) MCS | UE3(2) MCS |
| 3963 | 5 | 15 | 25 |
| 3964 | 1 | 10 | 20 |
| 3965 | 5 | 15 | 25 |
| 3966 | 1 | 10 | 20 |
| 3967 | 5 | 15 | 25 |
| 3968 | 1 | 10 | 20 |
| 3969 | 5 | 15 | 25 |
| 3970 | 1 | 10 | 20 |

Problem 2

Flowchart:

A close up of a logo

Description automatically generated

Validation scenario used to generate Gnuplots:

./waf --run "scratch/prj5\_px --OutputFileName=output/prj --Scenario=3 --NumberUE=1 --Transport=1 --wifiMcs=HtMcs7 --tcpRcvBufBytes=1024000 --DataSizeforTCP=5000000 --DataRateforUDP=200Mb/s --delayValueforRHtoR=5 --delayValueforLte=50 --delayValueforWifi=10 --simTime=2 --aggPath=lteAndWifi --inOrderTimeout=100"

Scenario includes a dropped packet #100

Gnuplots:

We can see the delay is not greater than our timeout period of 100ms.

A screenshot of a social media post

Description automatically generated

We can see some of the packets are out of sequence when they are received by RecvQueue.

A picture containing screenshot

Description automatically generated

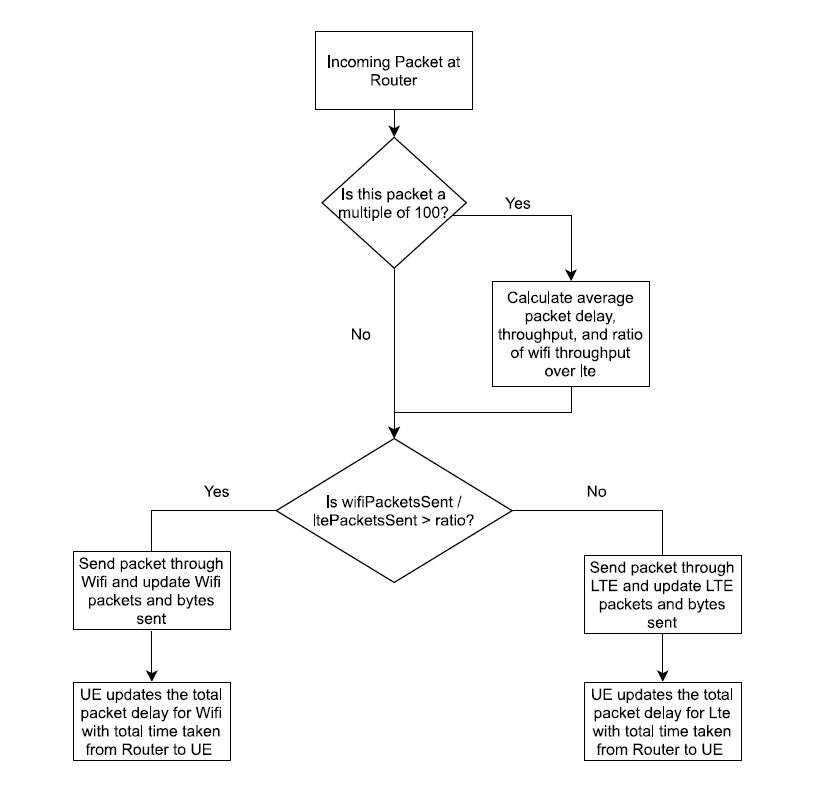
We can see the packets are all in order when sent to the upper layer.

A screenshot of a cell phone

Description automatically generated

**Problem 3:**

Flowchart:



Implementation:

1. Created global variables in lines 73-80:
   1. lteBytesSent
   2. ltePacketsSent
   3. wifiBytesSent
   4. wifiPacketsSent
   5. packetDelayWifi
   6. packetDelayLte
2. Inserted flowchart logic into rtVirtualSend function from lines 607-717
3. Updated the LTE & Wifi Tunnel receive functions to have the UE’s update packetDelayWifi & packetDelayLte with the packet delay for that individual packet.

Validation:

Updated the rtVirtualSend Function to show “LTE packet” or “wifiPacket” in the aggregation scenario to show on the cmd line whether a packet was being sent via lte or via wifi. Then the commands below were used to test the verification that the algorithm was working as intended. The following is the results of the aggregation scenario’s throughput vs. the Wifi & LTE only for 1UE:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RTT(ms) | RWND (Bytes) | MCS | 1 UE | | | | | |
| Per UE | | | | | |
| Wi-Fi TCP | | LTE TCP | | Aggregation TCP | |
| Peak (Mbps) | Avg (Mbps) | Peak (Mbps) | Avg (Mbps) | Peak (Mbps) | Avg (Mbps) |
| 30 ms | 64000 | HtMcs1 | 14.78 | 11.59 |  |  | 14.78 | 10.25 |
| 200 ms | 64000 | HtMcs1 | 5.04 | 2.37 |  |  | 5.04 | 3.71 |
| 30 ms | 1024000 | HtMcs1 | 24.08 | 21.62 |  |  | 81.9 | 14.03 |
| 200 ms | 1024000 | HtMcs1 | 23.86 | 13.56 |  |  | 73.93 | 21.62 |
| 30 ms | 64000 | HtMcs7 | 16.91 | 14.81 | 14.11 | 10.13 | 14.78 | 10.38 |
| 200 ms | 64000 | HtMcs7 | 5.04 | 2.67 | 4.93 | 2.20 | 5.04 | 3.50 |
| 30 ms | 1024000 | HtMcs7 | 114.69 | 80.00 | 72.58 | 50.00 | 158.70 | 66.66 |
| 200 ms | 1024000 | HtMcs7 | 60.03 | 17.78 | 72.46 | 16.67 | 75.60 | 22.22 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| RTT | MCS | 1 UE | | | | | |
| System Level | | | | | |
| Wi-Fi UDP | | LTE UDP | | Aggregation UDP | |
| Peak (Mbps) | Avg (Mbps) | Peak (Mbps) | Avg (Mbps) | Peak (Mbps) | Avg (Mbps) |
| 30 ms | HtMcs1 | 25.20 | 25.09 |  |  | 50.4 | 50.02 |
| 200 ms | HtMcs1 | 25.09 | 25.09 |  |  | 66.19 | 49.97 |
| 30 ms | HtMcs7 | 121.97 | 121.73 | 73.70 | 73.70 | 151.76 | 150.16 |
| 200 ms | HtMcs7 | 121.97 | 121.73 | 73.70 | 73.70 | 178.86 | 158.74 |

Commands used:

TCP –

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m7\_rw1m\_rtt30 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs7 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=1024000 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m1\_rw1m\_rtt30 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs1 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=1024000 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m7\_rw64k\_rtt30 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs7 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=64000 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m1\_rw64k\_rtt30 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs1 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=64000 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m7\_rw1m\_rtt200 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs7 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=1024000 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m1\_rw1m\_rtt200 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs1 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=1024000 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m7\_rw64k\_rtt200 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs7 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=64000 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=20 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_10m\_tcp\_1ue\_m1\_rw64k\_rtt200 --Scenario=3 --NumberUE=1 --wifiMcs=HtMcs1 --Transport=1 --DataSizeforTCP=10000000 --tcpRcvBufBytes=64000 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=20 --aggPath=lteAndWifi"

UDP –

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_50Mb\_udp\_1ue\_m1\_rtt30 --Scenario=3 --NumberUE=1 --Transport=2 --DataRateforUDP=50Mb/s --wifiMcs=HtMcs1 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=3 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_150Mb\_udp\_1ue\_m7\_rtt30 --Scenario=3 --NumberUE=1 --Transport=2 --DataRateforUDP=150Mb/s --wifiMcs=HtMcs7 --delayValueforRHtoR=5 --delayValueforWifi=10 --delayValueforLte=10 --simTime=3 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_50Mb\_udp\_1ue\_m1\_rtt200 --Scenario=3 --NumberUE=1 --Transport=2 --DataRateforUDP=50Mb/s --wifiMcs=HtMcs1 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=3 --aggPath=lteAndWifi"

./waf --run "scratch/prj5\_px --OutputFileName=output/prj\_150Mb\_udp\_1ue\_m7\_rtt200 --Scenario=3 --NumberUE=1 --Transport=2 --DataRateforUDP=150Mb/s --wifiMcs=HtMcs7 --delayValueforRHtoR=10 --delayValueforWifi=90 --delayValueforLte=90 --simTime=3 --aggPath=lteAndWifi"