LAB 2 LTE module

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D7030E Advanced Wireless Networks

LAB 2 LTE module

by

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Tasks

1.1. Write simulation scenario.

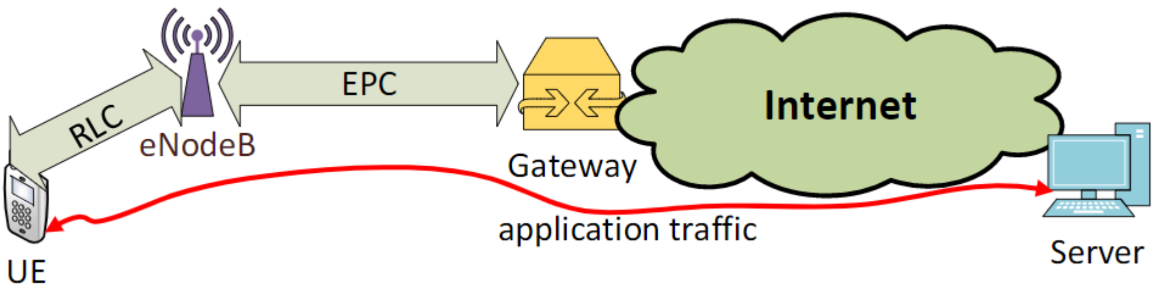

Figure 1.1: Scenario for the Lab

The scenario detailed above describes in details an LTE topology for when a UE (User Equipment) wants to communicate with the Server for an OnOff Application traffc. Using the layer 2 RLC (Radio Link Protocol), the UE first makes connection with eNodeB (which is responsible for numerous functions such as Radio Resource Management, Radio Bearer Control, Selection of MME at LTE UE attachment and so on). Using EPC (Evolved Packet Core) framework, the data is transmitted via the gateway to the server.

1.1.1. Specification for scenario:

1. “ns3::LteAmc::AmcModel": LteAmc::PiroEW2010
2. Attributes for LteHelper
    (a) Pathloss model:TwoRayGroundPropagationLossModel
    (b) SchedulerType: PfFfMacScheduler
    (c) DlEarfcn: 100
    (d) UlEarfcn: 18100
    (e) DlBandwidth=UlBandwidth: 50
3. Three different antenna configurations (parabolic, cosine and isotropic) is used
4. Routing between the Server and the UE is enabled
5. Application OnOff uses OnOffHelper with “UdpSocketFactory" and is deployed on a server
6. PCAP trace from the server’s side is recorded
7. Traces from LteHelper are recorded

The scenario was adapted from (Osipov, 2021).

1.2. Be able to describe the content of traces from LTE system.

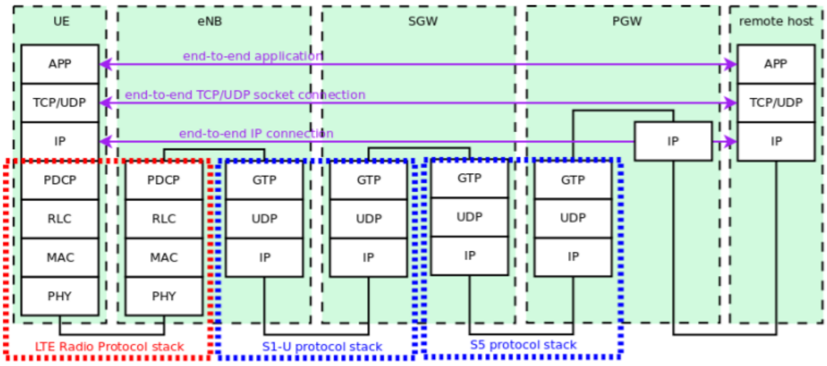

Figure 1.2: LTE Module

For trace of the resource allocation as noted down by the scheduler upon the start of every subframe, MAC KPIs are used.

For downlink MAC KPIs the format is the following:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. Frame number
5. Subframe number
6. cell-specific UE ID (RNTI)
7. MCS of TB 1
8. size of TB 1
9. MCS of TB 2 (0 if not present)
10. size of TB 2 (0 if not present)

For uplink MAC KPIs the format is:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. Frame number
5. Subframe number
6. cell-specific UE ID (RNTI)
7. MCS of TB
8. size of TB

The columns of the RLC KPI files is the following (the same for uplink and downlink):

1. start time of measurement interval in seconds since the start of simulation
2. end time of measurement interval in seconds since the start of simulation

3. Cell ID
4. unique UE ID (IMSI)
5. cell-specific UE ID (RNTI)
6. Logical Channel ID
7. Number of transmitted RLC PDUs
8. Total bytes transmitted.
9. Number of received RLC PDUs
10. Total bytes received
11. Average RLC PDU delay in seconds
12. Standard deviation of the RLC PDU delay
13. Minimum value of the RLC PDU delay
14. Maximum value of the RLC PDU delay
15. Average RLC PDU size, in bytes
16. Standard deviation of the RLC PDU size
17. Minimum RLC PDU size
18. Maximum RLC PDU size

Likewise, the columns of the PDCP KPI files is the following (again, the same for uplink and downlink):

1. start time of measurement interval in seconds since the start of simulation
2. end time of measurement interval in seconds since the start of simulation
3. Cell ID
4. unique UE ID (IMSI)
5. cell-specific UE ID (RNTI)
6. Logical Channel ID
7. Number of transmitted PDCP PDUs
8. Total bytes transmitted.
9. Number of received PDCP PDUs
10. Total bytes received
11. Average PDCP PDU delay in seconds
12. Standard deviation of the PDCP PDU delay
13. Minimum value of the PDCP PDU delay
14. Maximum value of the PDCP PDU delay
15. Average PDCP PDU size, in bytes
16. Standard deviation of the PDCP PDU size
17. Minimum PDCP PDU size

18. Maximum PDCP PDU size

MAC KPIs are basically a trace of the resource allocation reported by the scheduler upon the start of every subframe. They are stored in ASCII files. For downlink MAC KPIs the format is the following:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. Frame number
5. Subframe number
6. cell-specific UE ID (RNTI)
7. MCS of TB 1
8. size of TB 1
9. MCS of TB 2 (0 if not present)
10. size of TB 2 (0 if not present)

while for uplink MAC KPIs the format is:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. Frame number
5. Subframe number
6. cell-specific UE ID (RNTI)
7. MCS of TB
8. size of TB

In the RSRP/SINR file, the following content is available:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. RSRP
5. Linear average over all RBs of the downlink SINR in linear units

The contents in the UE SINR file are:

1. Simulation time in seconds at which the allocation is indicated by the scheduler
2. Cell ID
3. unique UE ID (IMSI)
4. uplink SINR in linear units for the UE

In the interference filename the content is:

1. Simulation time in seconds at which the allocation is indicated by the scheduler

2. Cell ID
3. List of interference values per RB

In UL and DL transmission files the parameters included are:

1. Simulation time in milliseconds
2. Cell ID
3. unique UE ID (IMSI)
4. RNTI
5. Layer of transmission
6. MCS
7. size of the TB
8. Redundancy version
9. New Data Indicator flag

And finally, in UL and DL reception files the parameters included are:

1. Simulation time in milliseconds
2. Cell ID
3. unique UE ID (IMSI)
4. RNTI
5. Transmission Mode
6. Layer of transmission
7. MCS
8. size of the TB
9. Redundancy version
10. New Data Indicator flag
11. Correctness in the reception of the TB

The description of the simulation traces were adapted from (ns3, 2021).

1.3. Describe which differences in traces you have observed for different antenna configurations(parabolic, cosine and isotropic). Especially, observe cases, when UE is not aligned with antenna's direction (possible only for parabolic and cosine antennas).Do not be surprised you do not see large difference in results for parabolic and cosine antennas.

The radiation patterns of the different antennas are as follows:

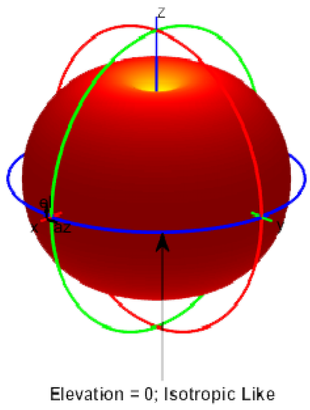

Figure 1.3: Isotropic Antenna Radiation Pattern

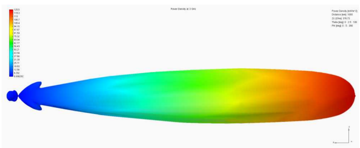

Figure 1.4: Parabolic Antenna Radiation Pattern

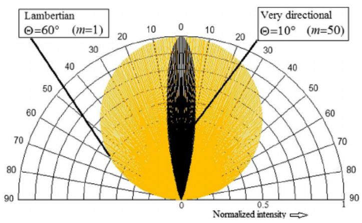

Figure 1.5: Cosine Antenna Radiation Pattern

All the trace files were observed. As there are numerous trace files, the files that were most relevant were chosen. The best way to measure data received is using throughput, which is done using RLC statistics for both Downlink and Uplink (telecomhallforum, 2020). Another great way to observe is measuring the SINR (Signal to Interference & Noise Ratio) for both downlink and uplink as it denotes the signal strength (ns3, 2021).

The data rate is fixed at 50 Mbps for all antennas. The distance between the UE and eNodeB is set at 1 metres along the x axis for all antennas as well.

Throughput is calculated from the RLC trace files. This is because the RLC layer contains the PDCP layer data encapsulated as well.

The throughput is calculated as follows:

$$DownlinkThroughput = \frac{\sum(DlRxBytes) * 8 * 10^{-3}}{\text{simulation time}} \tag{1.1}$$

where

DlRxBytes is the 10-th column of the trace file DlRlcStats.txt

Simulation time is for how long the simulation runs which is set as 5 for this scenario

It is multiplied by 8 to convert it to bits and by 10^{-3} to convert it to kbps.

$$UplinkThroughput = \frac{\sum(UlRxBytes) * 8 * 10^{-3}}{\text{simulation time}} \tag{1.2}$$

where

UlRxBytes is the 10-th column of the trace file UlRlcStats.txt
Simulation time is for how long the simulation runs which is set as 5 for this scenario
It is multiplied by 8 to convert it to bits and by 10^{-3} to convert it to kbps.

Average SINR in Decibels is calculated from RsrpSinrStats trace files as follows:

$$DlAverageSinrDb = 10 * log_{10}(mean(DlSinr)) \tag{1.3}$$

where
DLSinr is the 6th column of the trace file DlRsrpSinrStats.txt

$$UlAverageSinrDb = 10 * log_{10}(mean(UlSinr)) \tag{1.4}$$

where
ULSinr is the 6th column of the trace file UlRsrpSinrStats.txt

Isotropic antenna is considered to be an ideal antenna model. It can work omnidirectionally. Therefore, it does not need any specific orientation or beamwidth. It can also be observed that isotropic antennas produces the highest throughput and SINR in both uplink and downlink. Similarly for numerous orientations, parabolic antennas produce the same result in case of throughput for all orientations and beamwidth although the DL SINR is lower than that of isotropic. The case of the cosine antenna is the most interesting as it offers variations with beamwidth and orientations. For orientation of 90 degrees along x-axis, the receiver starts receiving data from a beamwidth of 34 degrees and reaches its maximum at beamwidth of 42 degrees.

The results are demonstrated in a tabular manner as well as graphically.

Table 1.1: Throughput and SINR for different antennas for different orientation and beamwidth

Orientation (deg)	Beamwidth (deg)	Antenna	DL Avg. Throughput (kbps)	UL Avg. Throughput (kbps)	DL Avg. SINR (dB)	UL Avg. SINR (dB)
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	34	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	34	Cosine	1.32	0	0	0
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	35	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	35	Cosine	1.32	0	0	0
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	38	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	38	Cosine	9475.96	536.9328	11.19177	9.007352
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	40	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	40	Cosine	18974.234	1074.504	18.56667	16.38225
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	41	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	41	Cosine	2.53E+04	1428.4208	21.85607	19.67164
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	42	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	42	Cosine	3.50E+04	1.98E+03	24.91332	22.7289
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	60	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
90	60	Cosine	3.50E+04	1.98E+03	56.49248	37.26285
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
0	40	Parabolic	3.50E+04	1.98E+03	86.48307	37.26285
0	40	Cosine	3.50E+04	1.98E+03	56.49248	37.26285
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
0	60	Parabolic	3.50E+04	1.98E+03	86.48307	37.26285
0	60	Cosine	3.50E+04	1.98E+03	86.48307	37.26285
N/A	N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
180	60	Parabolic	3.50E+04	1.98E+03	66.48307	37.26285
180	60	Cosine	0.00E+00	0.00E+00	- inf	- inf

Graphs are plotted only for orientation of 90 degrees since this offered the greatest changes.

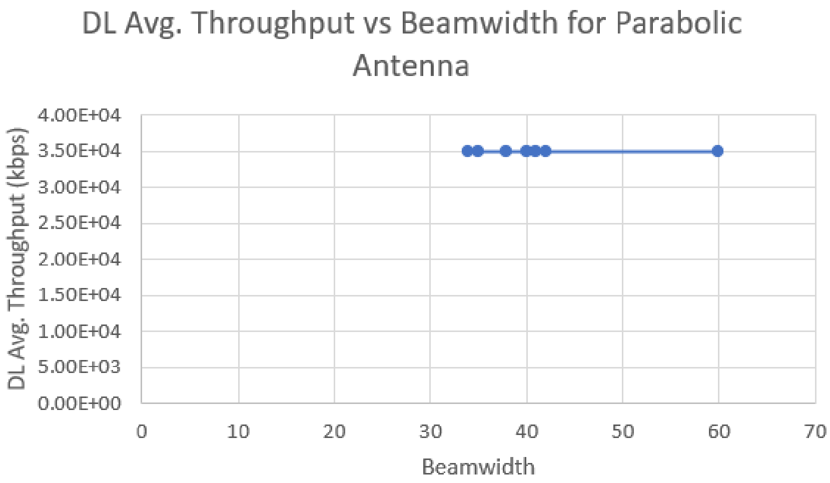

Figure 1.6: DL Throughput vs Beamwidth for Parabolic Antennas

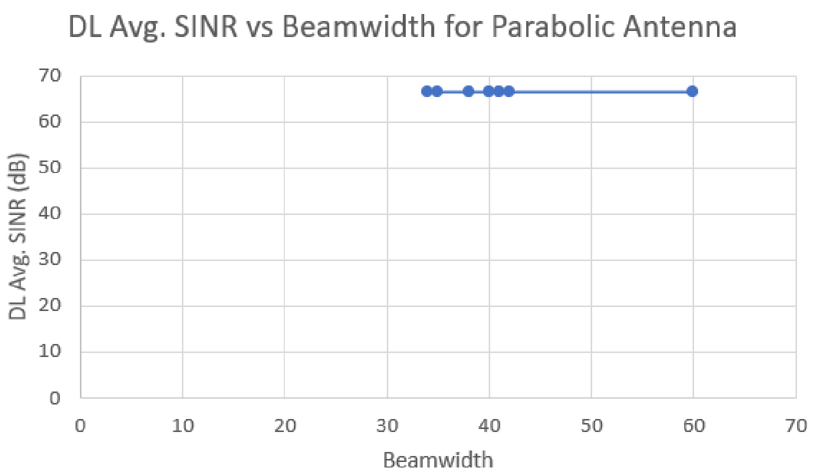

Figure 1.7: DL SINR vs Beamwidth for Parabolic Antennas

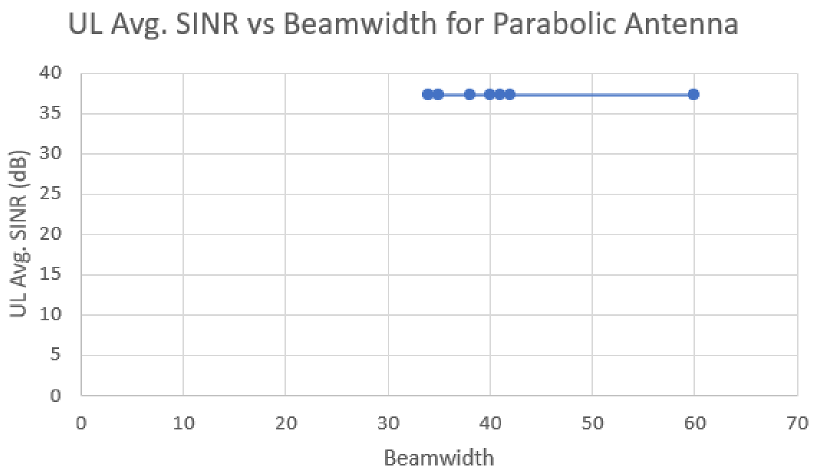

Figure 1.8: UL SINR vs Beamwidth for Parabolic Antennas

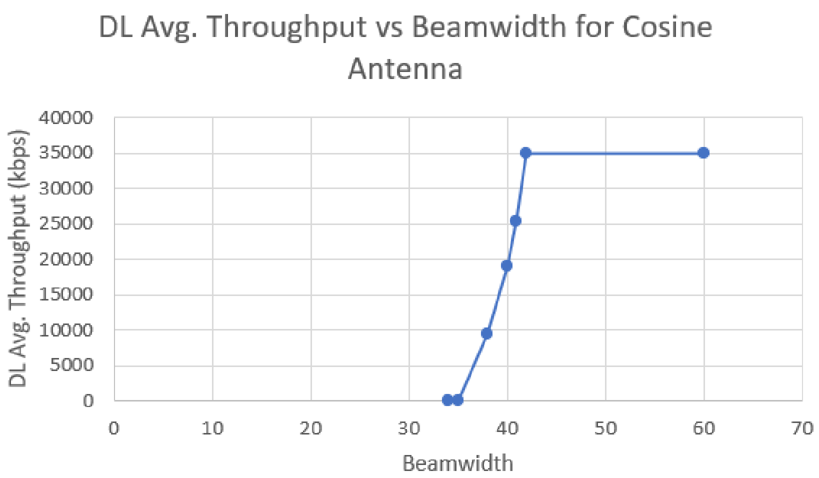

Figure 1.9: DL Throughput vs Beamwidth for Cosine Antennas

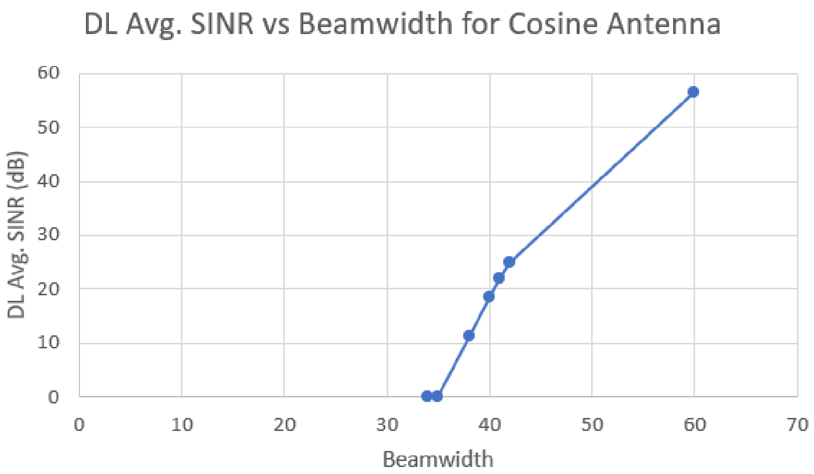

Figure 1.10: DL SINR vs Beamwidth for Cosine Antennas

Figure 1.11: UL SINR vs Beamwidth for Cosine Antennas

Since distance of 1 metre did not provide substantial changes, another experiment was done with a fixed beamwidth of 30 degrees and distance between UE and eNodeB at 1000 metres. A larger distance shows more prominent results. It can be observed that as the direction of the antenna (for cosine and parabolic) moves away from the UE position, it receives less and less information, until at about 30 degrees (as set due to the beamwidth), it can no longer receive any data.

Table 1.2: Throughput and SINR for different antennas for different orientation at 1000 metres

Orientation (deg)	Antenna	DL Avg. Throughput (kbps)	UL Avg. Throughput (kbps)	DL Avg. SINR (dB)	UL Avg. SINR (dB)
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
0	Parabolic	4941.2448	279.5552	5.457573	2.457569
0	Cosine	4941.2448	279.5552	5.457573	2.457569
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
15	Parabolic	3477.6992	279.56	2.4576	-0.54242
15	Cosine	3477.6992	196.4176	2.457569	-0.54242
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
30	Parabolic	2.64E+00	279.56	-6.54242	-9.54243
30	Cosine	2.64	196.4176	-6.64733	-9.64734
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
45	Parabolic	0.00E+00	279.56	-14.5424	-17.5424
45	Cosine	0.00E+00	196.4176	-22.187	-25.187
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
90	Parabolic	0.00E+00	279.56	-14.5424	-17.5424
90	Cosine	0.00E+00	196.4176	-115.554	-118.554
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
180	Parabolic	0.00E+00	279.56	-14.5424	-17.5424
180	Cosine	0.00E+00	196.4176	-115.554	-118.554
N/A	Isotropic	3.50E+04	1.98E+03	86.48307	37.26285
270	Parabolic	0.00E+00	279.56	-14.5424	-17.5424
270	Cosine	0.00E+00	196.4176	-115.554	-118.554

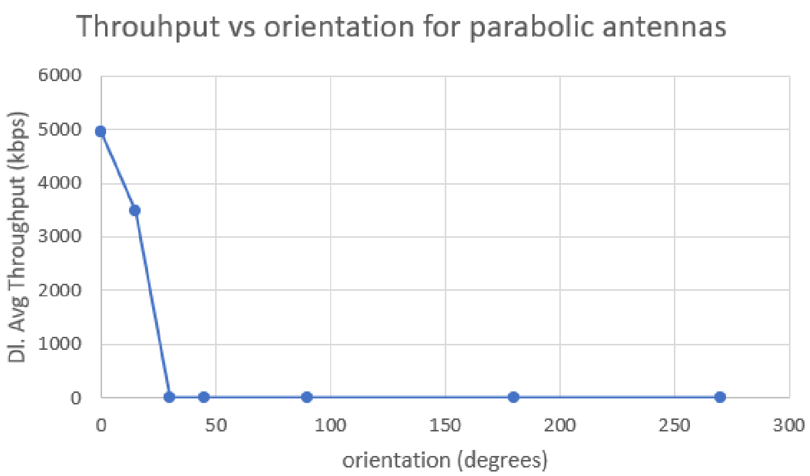

Figure 1.12: DL Throughput vs Orientation for Parabolic Antennas for 1000 metres

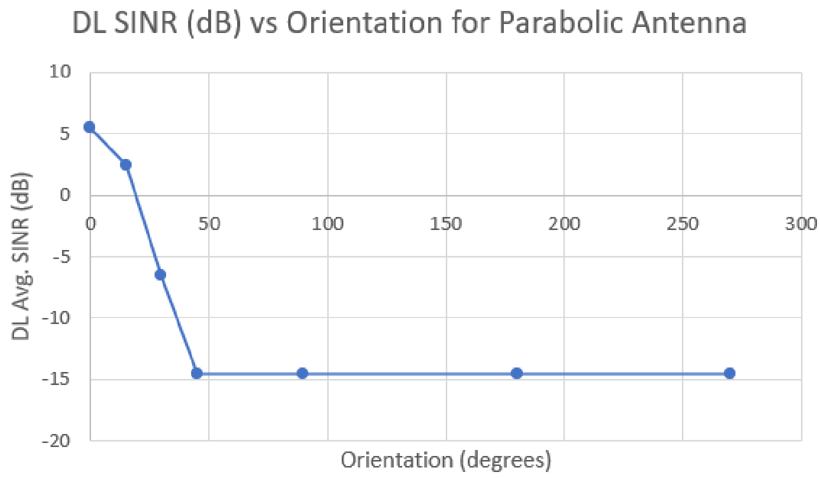

Figure 1.13: DL SINR vs Orientation for Parabolic Antennas for 1000 metres

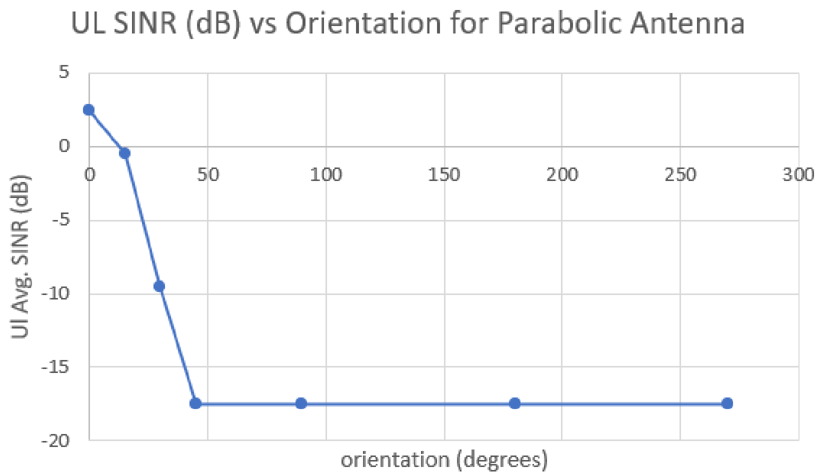

Figure 1.14: UL SINR vs Orientation for Parabolic Antennas for 1000 metres

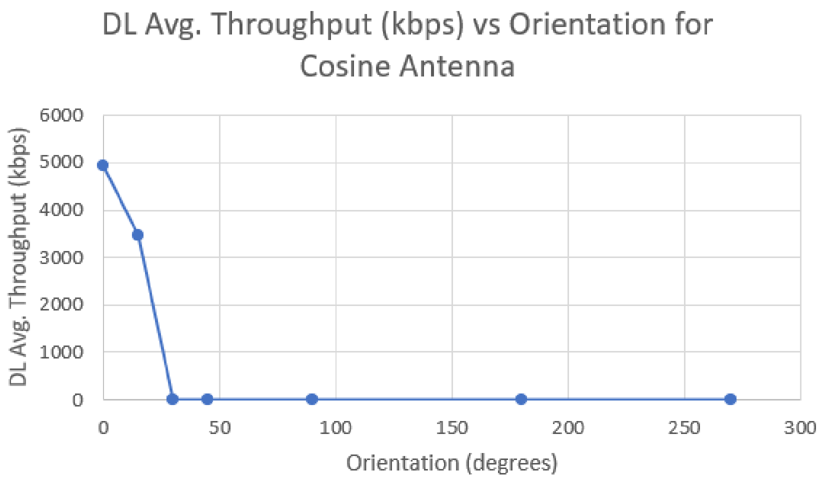

Figure 1.15: DL Throughput vs Orientation for Cosine Antennas for 1000 metres

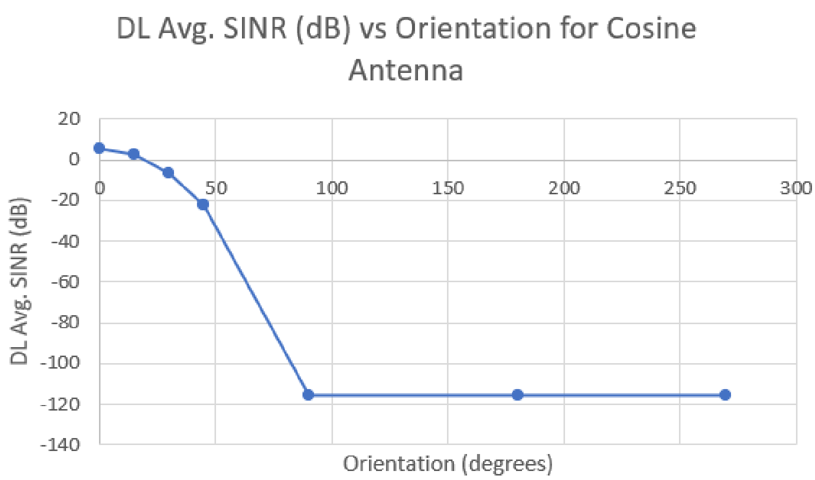

Figure 1.16: DL SINR vs Orientation for Cosine Antennas for 1000 metres

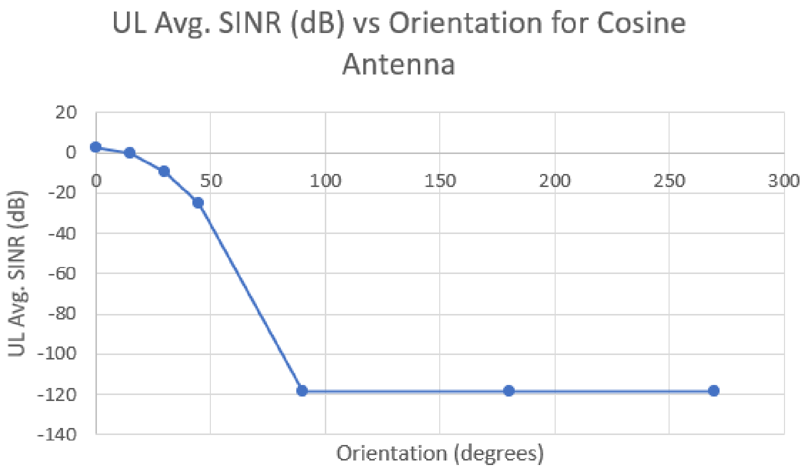

Figure 1.17: UL SINR vs Orientation for Cosine Antennas for 1000 metres

1.4. Calculate the throughput between the eNodeB and UE for 3 different application's Datarates (determine them on your own) but choose them such that there is a notable difference in the calculated throughput

The orientation is fixed at 90 degrees and beamwidth is fixed at 60 degrees for all the antennas (except isotropic since it does not need orientation and beamwidth specifications). The distance between the UE and ENodeB is set at 1 metres along the x axis.

Different Data-Rates are experimented for all 3 types of antenna. It can be observed that with increase in Data-Rate, the throughput increases. The throughput increases with data-rate until it plateaus off at the highest value at 35 Mbps. This is because this is the highest throughput the system can support. Another interesting point to note is that although for increasing data rates the throughput increased, the values for the throughput for all three antennas for a particular data remained the same. DL throughput values are much larger than UL throughput.

The results are demonstrated in a tabular manner as well as graphically.

Table 1.3: Throughput for different antennas for different data-rate

Data-Rate (Mbps)	Antenna	DL Avg. Throughput (kbps)	UL Avg. Throughput (kbps)
1	Isotropic	1025.6	58.176
1	Parabolic	1025.6	58.176
1	Cosine	1025.6	58.176
10	Isotropic	10264.33	582.63
10	Parabolic	10264.33	582.63
10	Cosine	10264.33	582.63
20	Isotropic	20520.08	1161.4
20	Parabolic	20520.08	1161.4
20	Cosine	20520.08	1161.4
30	Isotropic	30766.45	1738.9
30	Parabolic	30766.45	1738.9
30	Cosine	30766.45	1738.9
33	Isotropic	33842.68	1913.2
33	Parabolic	33842.68	1913.2
33	Cosine	33842.68	1913.2
34	Isotropic	34873.28	1970.4
34	Parabolic	34873.28	1970.4
34	Cosine	34873.28	1970.4
35	Isotropic	34964.38	1975.4
35	Parabolic	34964.38	1975.4
35	Cosine	34964.38	1975.4
40	Isotropic	34964.38	1975.4
40	Parabolic	34964.38	1975.4
40	Cosine	34964.38	1975.4
50	Isotropic	34964.38	1975.4
50	Parabolic	34964.38	1975.4
50	Cosine	34964.38	1975.4
100	Isotropic	34964.38	1975.4
100	Parabolic	34964.38	1975.4
100	Cosine	34964.38	1975.4

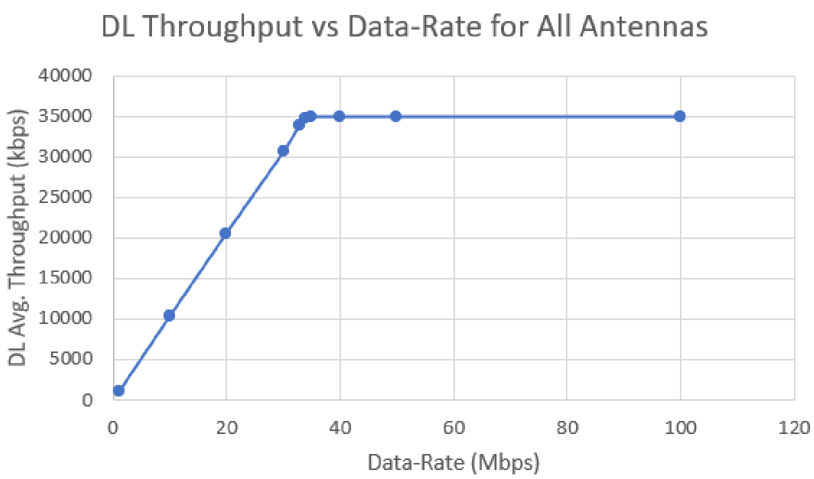

Figure 1.18: DL Throughput vs DataRate for All Antennas

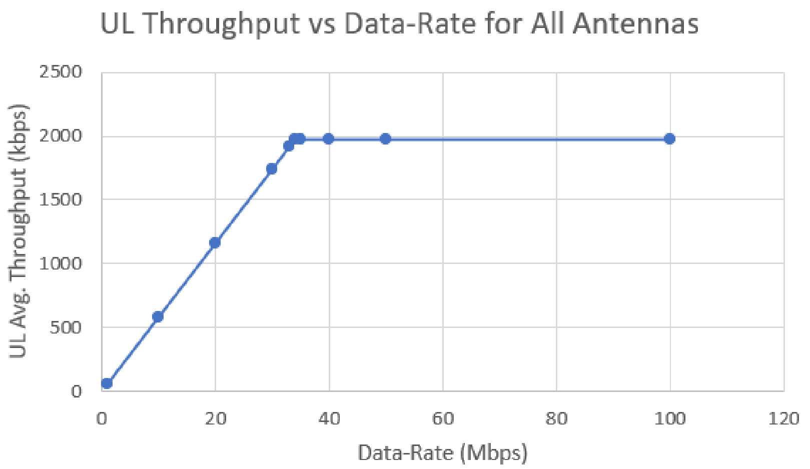

Figure 1.19: UL Throughput vs DataRate for All Antennas

1.5. Calculate the throughput between the eNodeB and UE for one fixed application's DataRate (choose yourself and motivate your choice) and different distances between eNodeB and UE for the isotropic antenna type.

The data rate for the application is set as 50 Mbps for all the experiments in this question. Since isotropic antenna does not require orientation or beadwidth, these values are not set in this instance.

Equations (1.1) and (1.2) are also used in this instance to calculate the throughput.

Different distances are experimented for isotropic antenna. It can be observed that with increase in distance, the throughput decreases. This is because it becomes more difficult for the signal to reach the receiver. The throughput remains constant at the maximum for approximately about 300 metres and reduces with an exponential decay pattern for further increase of distance until about 2000 metres, where it has minimal throughput until it turns to zero with ever further increase of distance. Similar to 1.4, DL throughput values are much higher than UL throughput.

The results are demonstrated in a tabular manner as well as graphically.

Table 1.4: Throughput for different antennas for different distances

Distance (m)	Antenna	DL Avg. Throughput (kbps)	UL Avg. Throughput (kbps)
1	Isotropic	34964.38	1975.4
50	Isotropic	34964.38	1975.4
100	Isotropic	34964.38	1975.4
300	Isotropic	34964.38	1975.4
500	Isotropic	18974.23	1074.504
1000	Isotropic	4941.245	279.5552
1500	Isotropic	1309.1232	0.192
2000	Isotropic	2.64	0.192
2200	Isotropic	1.32	0.192
2500	Isotropic	0	0.192

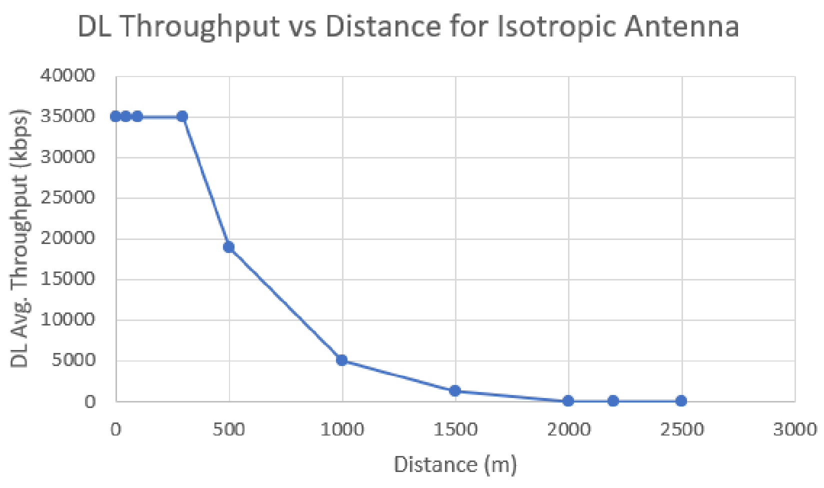

Figure 1.20: DL Throughput vs Distance for Isotropic Antenna

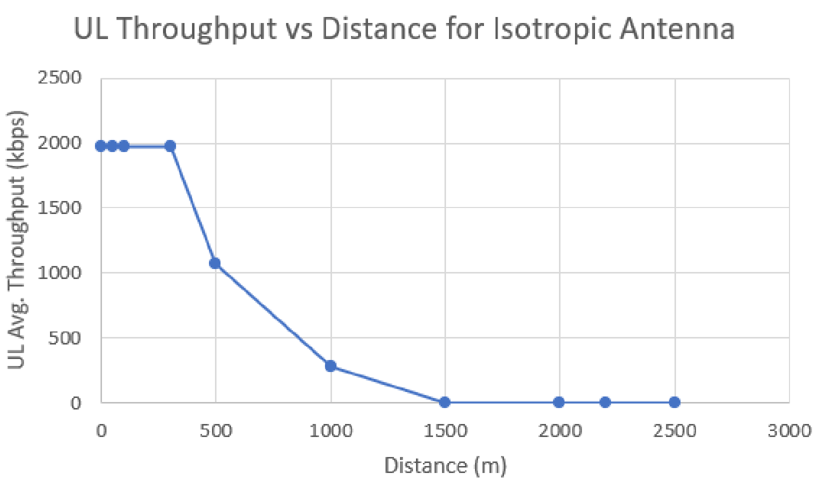

Figure 1.21: UL Throughput vs Distance for Isotropic Antenna

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