IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 16, Issue 2, Ser. I (Mar - Apr 2021), PP 27-40
www.iosrjournals.org

Computational Analysis of Optimal Splitter Coordinates for Passive Optical Network (PON) Deployment

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Abstract
Passive Optical Networks (PONs) is seen as a potential backhaul for 4G (LTE) mobile networks because of its excellent technical attributes like capacity, reliability, range and lots more. Determination of optimal location for its splitter is important because of its role in getting total fibre length required for PON network deployment. This paper presents computational techniques for determination of optimal splitter coordinates for Passive Optical Networks. SMILE Mobile Networks Port Harcourt was used as a case study. Cell finder tool was used to obtain the coordinates of all SMILE eNB locations in Port Harcourt. Two methods (Manual and Systematic) were developed. In manual method, 35 sample test splitter locations were considered via the aid of GPS Visualizer tool and the coordinate 4.8277864^{0}N, 7.026582^{0}E was obtained as optimal splitter coordinate. Systematic approach utilises Vincenty formula for coordinates, the equations generated were modelled in MATLAB simulation environment to get optimal splitter location with coordinates 4.8276^{0}N, 7.0254^{0}E. The results obtained from both approaches were compared and they presented very close similarities, hence produced minimal length of optical fibre for passive optical network deployment.

Keywords: *LTE, PON, Coordinates, Optimum, Splitter, Optical Network Unit, Optical Line Terminal, eNB*

Date of Submission: 18-03-2021 Date of Acceptance: 02-04-2021

I. Introduction

With the increasing demand for higher speed internet connectivity for long term evolution 4G (LTE) and the anticipated revolution of 5G, most network service providers are fast replacing their legacy copper-based access infrastructures with new fibre based technologies (Mateusz Zotkiewicz et al, 2016). Recently, the required backhaul capacity has significantly increased due to the increasing population of mobile subscribers and the availability of mobile high-speed data services. The increasing number of mobile subscribers has resulted in a significant growth in the number of deployed base station sites (Orawan Tipmongkolsilp et al, 2010). Passive Optical Network PON has been widely accepted to fit in to this role of backhaul because of its cost effectiveness as compared to point to point active fibre networks. PON being fibre optics technology utilizes the combination of the good attributes of fibre like unlimited range, unlimited capacity and excellent reliability with PON's cost effectiveness. This paper describes an efficient PON backhaul strategy for a 4G wireless network, focusing on the most efficient location for the splitter unit that plays a huge part in Passive Optical Networks (PON) deployement. PON saves the cost of running point –to point fibre (from one node to the other), instead, use a single fibre up to a point called splitter, the splitter will split signals into different Optical Network Units (ONUs). This makes it easier to achieve fibre to the home (FTTH) in the access network. Secondly, the cost of maintaining the active components in a point to-point network contributes heavily to the OPEX of the operators but PON uses passive component that will not require much maintenance thereby saving the operator huge sum. Again, fibre Point to point links requires 2 transceivers (1:1 transceiver), but PON uses one transceiver at the OLT to communicate several transceivers at ONUs (1: N transceiver).To substantiate the claim that PON reduces the cost of fibre deployments, research carried out by (Chathurika Ranaweera et al, 2013), demonstrated that PON deployment can save up to 50% of deployment cost associated with small cell backhauling in comparison to a typical Point to point fibre backhaul approach. Figure 1 is the result of their work. The equipment cost increases as the split ratio decreases.

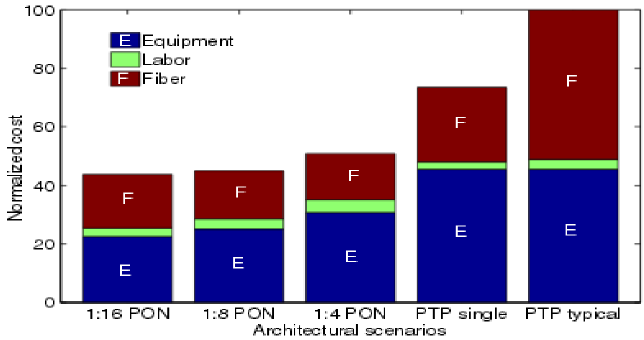


Figure 1: Cost –Equipment Analysis, (Chathurika Ranaweera et al, 2013)

Passive optical network is simply a point-to- multipoint/multipoint-point optical network in which information (voice, data, video, etc) is shared optically between one point called the optical line terminal (OLT) and other points called optical network units (ONUs). A typical PON network consists of central node called OLT and a number of ONUs with fibre link and splitter(s) in between them. Optical line terminal is the interface between the PON and the backbone network (core network), likewise ONU is the interface to the end user. In Time Division Multiplexing (TDM) PON, Data/signal is broadcast from OLT to many ONUs in the downstream direction and encryption is used to ensure that information/data meant for a particular ONU is not read by another. In the upstream, data / signal from many ONUs are combined using multiple access protocol like time division multiple access (TDMA) to one OLT. This allows for a two-way traffic on a single optical fibre cable (PON Powerpoint, 2016). The word passive in the PON means that the optical components used in the PON network are non-powered (electrical devices are not used).

II. PON as a Cellular Backhaul

For clearer presentation and better understanding of this research, a case study of PON as a cellular backhaul for 4G (LTE) is considered using SMILE Communication Network Port Harcourt as a test bed. Evolved NodeB (eNB) locations/coordinates for SMILE 4G (LTE) Port Harcourt was obtained using Cell finder analytical tool. SMILE network has about sixty (60) eNBs in Port Harcourt area excluding Bonny axis according to Cell finder analytical tool.

Table 1 shows the coordinates of the smile eNBs in Port Harcourt. The coordinates and distribution of eNBs helped in determination of optimal splitter location. Assuming that the switch location houses the OLT and ONUs are housed by eNBs, the location of the splitter is imperative in determining minimal fibre cable length for a good design. Figure 2 shows tree topology passive optical network with varying splitter locations and the effect on fibre length of each ONU.

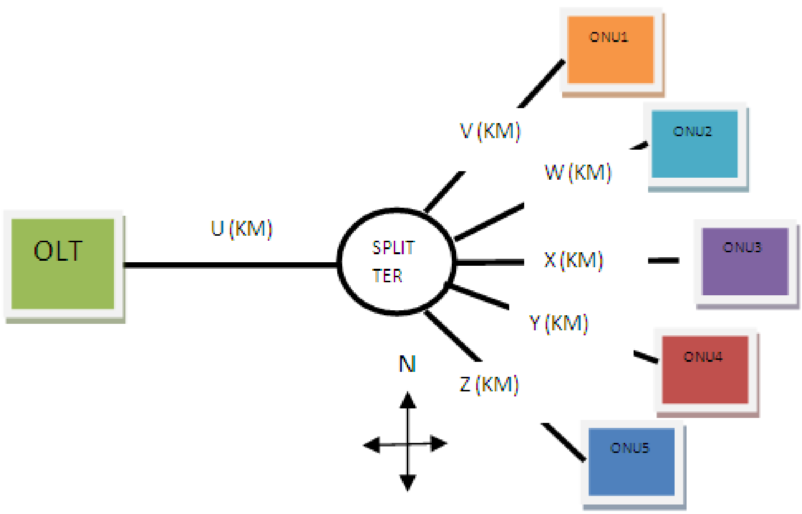


Figure 2: PON with Varying Splitter locations

Table 1: Smile eNBs and their coordinates in Port Harcourt

S/N	LAT 1(degree)	LONG 1(degree)	LAT (radian)	LONG1(radian)
eNB 1	4.83656	7.02861	0.084414	0.12267
eNB 2	4.77368	7.01428	0.083316	0.12242
eNB 3	4.799948	6.993902	0.083775	0.12207
eNB 4	4.829351	7.091902	0.084288	0.12378
eNB 5	4.770555	7.022393	0.083262	0.12256
eNB 6	4.874584	6.983038	0.085078	0.12188
eNB 7	4.869227	7.11365	0.084984	0.12416
eNB 8	4.71955	7.15183	0.082372	0.12482
eNB 9	4.855379	7.064134	0.084742	0.12329
eNB 10	4.790941	7.120734	0.083618	0.12428
eNB 11	4.785376	7.008187	0.083521	0.12232
eNB 12	4.832672	7.06854	0.084346	0.12337
eNB 13	4.803861	6.988323	0.083843	0.12197
eNB 14	4.81974	7.06564	0.08412	0.12332
eNB 15	4.743986	7.041728	0.082798	0.1229
eNB 16	4.79387	7.030763	0.083669	0.12271
eNB 17	4.748951	7.098856	0.082885	0.1239
eNB 18	4.777272	7.062001	0.083379	0.12326
eNB 19	4.834117	6.984506	0.084371	0.1219
eNB 20	4.856524	7.040508	0.084762	0.12288
eNB 21	4.806404	7.042423	0.083888	0.12291
eNB 22	4.814565	6.978764	0.08403	0.1218
eNB 23	4.829766	6.958811	0.084295	0.12145
eNB 24	4.892311	6.914281	0.085387	0.12068
eNB 25	4.847984	7.049188	0.084613	0.12303
eNB 26	4.851431	6.983489	0.084673	0.12188
eNB 27	4.808117	6.996657	0.083917	0.12211
eNB 28	4.90283	6.99907	0.085571	0.12216
eNB 29	4.978889	6.961111	0.086898	0.12149
eNB 30	4.62843	7.2701	0.080781	0.12689
eNB 31	4.996944	6.95	0.087213	0.1213
eNB 32	4.953889	7.011111	0.086462	0.12237
eNB 33	4.966944	6.986944	0.08669	0.12195
eNB 34	4.828889	7.021944	0.08428	0.12256
eNB 35	4.81687	7.01119	0.08407	0.12237
eNB 36	4.931694	7.002138	0.086074	0.12221
eNB 37	4.8407	6.96812	0.084486	0.12162
eNB 38	4.8597833	6.9791583	0.084819	0.12181
eNB 39	4.8469444	7.0369444	0.084595	0.12282
eNB 40	4.85847	6.96575	0.084796	0.12158
eNB 41	4.88	7.01	0.085172	0.12235
eNB 42	4.866944	7.03	0.084944	0.1227
eNB 43	4.837774	7.037036	0.084435	0.12282
eNB 44	4.884205	7.137983	0.085245	0.12458
eNB 45	4.781493	7.039845	0.083453	0.12287
eNB 46	4.811602	6.956136	0.083978	0.12141
eNB 47	4.90111	6.92694	0.085541	0.1209
eNB 48	4.90582	6.90656	0.085623	0.12054
eNB 49	4.802444	6.944	0.083818	0.1212
eNB 50	4.8354	7.05281	0.084394	0.12309
eNB 51	4.794722	7.049722	0.083684	0.12304
eNB 52	4.758056	7.011944	0.083044	0.12238
eNB 53	4.8269444	6.9961111	0.084246	0.12211
eNB 54	4.815	7.0419444	0.084038	0.12291
eNB 55	4.71	7.165	0.082205	0.12505
eNB 56	4.8233007	7.0571862	0.084182	0.12317
eNB 57	4.81532	7.06522	0.084043	0.12331

eNB 58	4.89497	7.0153	0.085433	0.12244
eNB 59	4.862628	7.015303	0.084869	0.12244
eNB 60	4.827644	7.01449	0.084258	0.12243

From figure 2, the length of fibre for each eNB/ONU is dependent on the position of the splitter. Moving the splitter to any direction of the cardinal point have a resultant increase/ decrease in the length of fibre for each ONU and also on the length between OLT – Splitter. One of the major challenges is how to get the optimal location for the splitter in any geographical environment, and that is the purpose of this research.

2.1 Determination of Optimal Splitter Location

PON technology having classic attributes to replacing copper-based technology in access networks, researches are ongoing on usage of PONs as cellular backhaul since it has excellent technical qualities suitable for a good backhaul. The big question is how does optimal location for the splitter determined? Splitter optimal location affords minimum attenuation, minimum fibre length as well as minimal cost for PON network design.

With reference to exchange/switch location, and taking the various locations of eNBs into considerations, this work tries to find a most suitable location for the splitter. It tries to find a place that could be closely located to all the eNBs, thus using the lowest amount of fibre for the PON design. This is necessary because if an optimal location is not chosen, the PON network design may end up using too many lengths of fibre which will result in a very expensive design, secondly, the attenuation accrued from the excess length of fibre will affect the power budget. Two methods ('Manual' and 'Systematic') were proposed in the determination of optimal splitter location.

2.1.1 Manual Method

This is done with the intention of analysing different locations for the splitter. For this research, thirty five (35) different sample locations were considered. The interest is to obtain the optimal location considering the fibre length in terms of walking distance, attenuation and cost effective design. This entails obtaining the walking distances (using Google map) from each splitter location to all the eNBs, and the exchange. Summation of these distances becomes the fibre length for the design. The location that has the minimum total distance becomes the optimum location. To achieve this procedure, one kilometer distance is moved from one base station (eNB point) towards another base station/ (eNB) as demonstrated in systematic 1 km movement of figure 3. This pattern is followed to generate up to thirty five (35) test splitter locations, from which the optimal location is chosen based on various great circle and walking distance calculations.

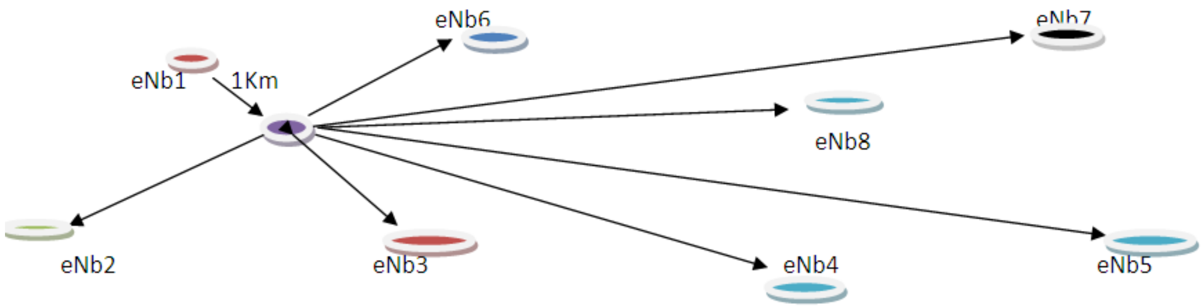


Figure 3: Systematic 1km movement to another eNB

To actualize one kilometer distance measurement, the facilities of the GPS VISUALIZER **(**www.gpsvisualizer.com**)** online platform was greatly used. Given the latitude and longitude coordinates of two test splitter locations, say location A and location B, this approach required that the coordinates of a point is obtained, one kilometer distance from point A towards point B, or one kilometer distance from point B towards point A. This coordinate generated is taken as a test splitter location. This system is continuously repeated with two random set of base station (eNB) points until required number of test splitter locations are generated, which in this case is thirty five (35). Apart from the latitude and longitude coordinates of the two chosen eNBs, one very important parameter that is needed is the "initial angle" between the two eNBs. This parameter (initial angle) is first generated using the GPS VISUALIZER before going ahead to get the test splitter coordinates.

To generate one test splitter location, the parameters needed are:

i) One kilometer distance
ii) Latitudes of the two eNBs
iii) Longitudes of the two eNBs
iv) Initial bearing (angle), which is first generated from the site.

The above listed parameters are as well needed for all other test splitter locations.
To illustrate the steps described above, the coordinates of eNB 5 and eNB 6 of table 1 was used to generate a test splitter location coordinate.
The coordinates of the eNBs are: eNB5 = 4.77055, 7.022393 and eNB6 = 4.874584, 6.983038
To get the initial bearing between these two locations using the GPS VISUALIZER platform, coordinates of eNB 5 is keyed in as 'lat.1, lon.1' while coordinates of eNB 6 is keyed in as 'lat.2, lon.2' as shown in figure 4. The value of initial angle is 339.348 degrees as obtained from the software.

Figure 4: Distance between two points (eNB 5 and eNB 6) and initial Bearing

With this initial angle, together with the coordinates of eNB 5 keyed in as 'Starting Lat.,Lon', the coordinates of the point which equals one kilometer distance from eNB 5 is obtained, it is shown as ' Ending Lat., Lon.'. This point becomes one test splitter location, and is given as 4.779053, 7.019198. Image on figure 5 shows the test splitter location.

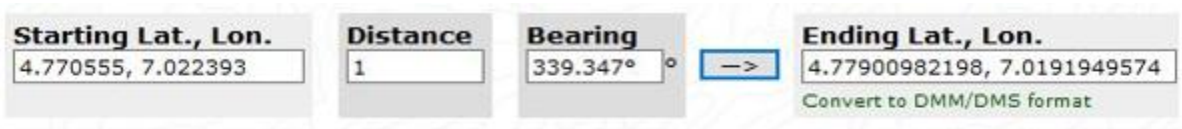


Figure 5: Test Splitter Location
Repeating the above procedures, all 35 test splitter location coordinates are obtained and compiled in the table 2.

Table 2: Test Splitter coordinates

S/N	LATITUDE	LONGITUDE
1	4.81107	7.06291
2	4.779053	7.019198
3	4.78084	7.008668
4	4.874229	6.992008
5	4.72719	7.146899
6	4.848612	7.07006
7	4.790461	7.111696
8	4.790971	7.015301
9	4.829653	7.060012
10	4.805706	6.997133
11	4.8277864	7.026582
12	4.788857	7.038283
13	4.753612	7.091832
14	4.782635	7.054722
15	4.83745	6.992874
16	4.847463	7.040843
17	4.848466	7.040197
18	4.842752	6.986136
19	4.81714	6.99692
20	4.91089	6.994971
21	4.82216	7.01589
22	4.825915	7.010485
23	4.923232	6.998936
24	4.848513	6.97264
25	4.857833	6.987999
26	4.848352	7.028002
27	4.841566	7.045196

28	4.877674	7.131759
29	4.784552	7.031315
30	4.820195	6.953296
31	4.903134	6.918115
32	4.897299	6.909675
33	4.805018	6.952629
34	4.826383	7.052113
35	4.78842	7.043214

For the purpose of optimization, the aim is to pick a splitter location where the total length of fiber that would be used will be a minimum value. The sum of the distances represents the total length of fibers and so, the table with the smallest sum represents the optimal splitter location. Table 3 shows all the thirty five test splitter locations and their summed distances from all eNBs and exchange as obtained using GP Visualizer and Google map.

Table 3: Splitter Locations and their cumulative Distances

S/N	SPLITTER LOCATION COORDINATES	GREAT CIRCLE DISTANCE (KM)	WALKING DISTANCE (KM)
1	4.81107, 7.06290	527.855	686.65
2	4.779053, 7.019198	554.338	784.1
3	4.78084, 7.008668	554.412	710.95
4	4.874229, 6.992008	539.374	678
5	4.72719, 7.146899	1151.32	1476.2
6	4.848612, 7.07006	554.225	672
7	4.790461, 7.111696	780.446	981.4
8	4.790971, 7.015301	511.928	685.8
9	4.829653, 7.060012	502.322	639.2
10	4.805706, 6.997133	489.956	649.95
11	4.8277864, 7.026582	440.7447	577.7
12	4.788857, 7.038283	527.233	694.1
13	4.753612, 7.091832	813.139	1280.8
14	4.782635, 7.054722	580.763	761.7
15	4.83745, 6.992874	472.145	599.3
16	4.847463, 7.040843	467.731	575
17	4.848466, 7.040197	468.21	579.45
18	4.842752, 6.986136	491.087	618.7
19	4.81714, 6.99692	470.952	608.5
20	4.91089, 6.994971	674.049	806.2
21	4.82216, 7.01589	443.611	567.95
22	4.825915, 7.010485	444.626	560.75
23	4.923232, 6.998936	727.148	857.8
24	4.848513, 6.97264	537.156	675.9
25	4.857833, 6.987999	507.063	653.6
26	4.848352, 7.028002	455.054	589.4
27	4.841566, 7.045196	468.762	596.6
28	4.877674, 7.131759	899.66	1141.4
29	4.784552, 7.0131315	535.772	726.8
30	4.820195, 6.953296	619.458	790.7
31	4.903134, 6.918115	891.147	1099.4
32	4.897299, 6.909675	916.504	1063.8
33	4.805018, 6.952629	647.412	872
34	4.826383, 7.052113	480.17	623.3

35	**4.78842, 7.043214**	**536.057**	**706.5**

Table 3 shows different values of both great circle and walking distances for each sample splitter location. Serial numbers 5 and 11 shows the highest and lowest value respectively in km for great circle distances. The corresponding walking distances shows that serial number 11 has 577.7km, which translate to the lowest fibre length. Figure 6 shows the coordinates of **4.8277864, 7.026582** on the map, the coordinates produced the lowest fibre length of 577.7km representing the optimal location from manual approach.

Figure 6: Optimal splitter location for Manual approach.

2.1.2 Automatic / Systematic Method

This approach uses algorithm and computer programming to achieve the purpose of finding the optimal splitter location that would require the least length of fiber for passive optical network deployment. The model automatically generated about 1,200 different test splitter locations using MATLAB programming tool. It generates the splitter locations, calculate and sum the distances between each splitter location and all eNbs, and finally extract the coordinates of the optimal splitter location. Note that for this model, distances are based on great circle calculations. The model is presented as follows: Assuming the positions of the eNBs, including the exchange, are located on the surface of the earth as depicted in figure 7

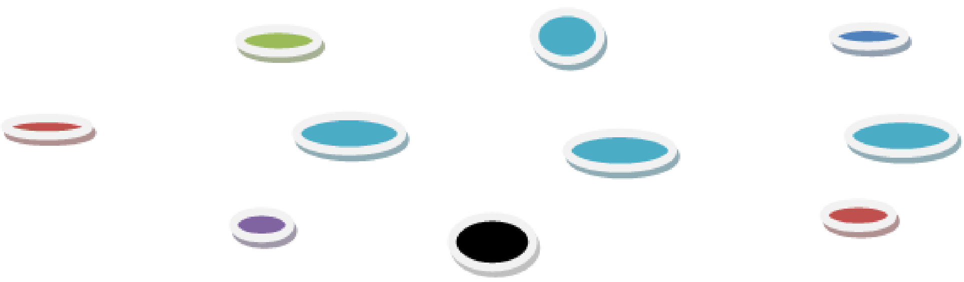


Figure 7: Assumed position of eNBs on the surface of earth

Imagine drawing a square around each eNB, each of the four vertices of each square becomes a test splitter location. Another square is drawn around each of these four vertices and their vertices each also becomes a test splitter location. This whole process in effect produces 20*N test splitter locations as shown in figure 8, where N is the number of eNBs including the exchange/switch. In this case of Smile Port Harcourt, it is 20 x 60 eNBs translating to 1200 test splitter locations. This is depicted in the figure 8 using one eNB.

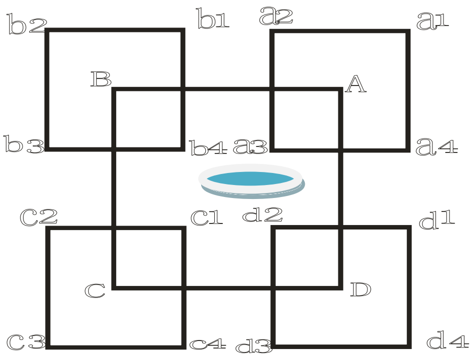


Figure 8: 20 Vertices of eNB

The method of obtaining the coordinates of the vertices is as follows:
Considering the earth as ellipsoidal in shape, for movement North or South (i.e. to cause a change in the reference latitude value), one degree is equivalent to about 111.1949 km. This is obtained from:

$$\left(\frac{\theta}{360}\right).(2\pi R)$$
(1)

Where R is the mean radius of the earth
For movement East or West (i.e. to cause a change in the reference longitude value), one degree is about 111.1949 multiplied by the cosine of the reference point latitude. The reference latitude is the latitude of the point desired to draw the square around while the reference longitude is the longitude of the same point. From the analysis above, it is demonstrated that;

$$\text{d(lat)} = \frac{r}{111.1949}$$
(2)

$$\text{d(lng)} = \frac{r}{(111.1949)}.\cos(lat)$$
(3)

Where;
d(lat) = change in latitude, **d(lng)** = change in longitude, **r** = the distance travelled east, west, north or south.
Since a square is been considered, then r will be half the length of a side of the square.

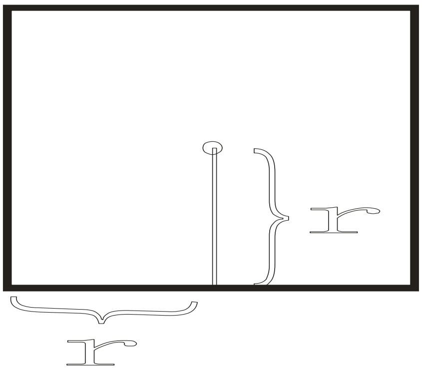


Figure 9: Half-length of a square

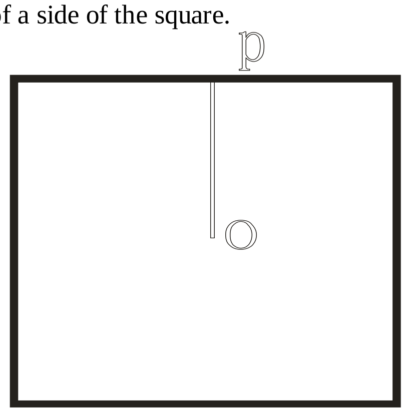
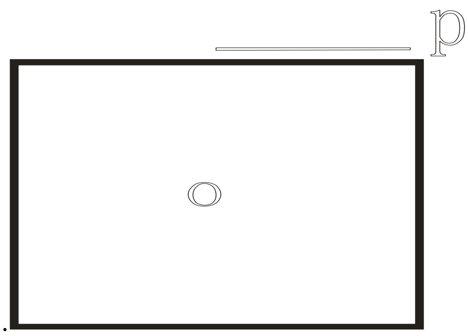


Figure 10: Change in latitude

For this analysis, r is taken to be 2km for the first set of squares and 1km for the second set. This is to ensure that any of the vertices will not overlap. To get the latitude of any vertex, the value of the change in latitude, d(lat) is added to the reference latitude if the vertex point is above the reference point, or subtract the value of the change in latitude, d(lat), from the reference latitude if the vertex point is below the reference point.

The latitude of the point P is got as the latitude of point O plus the change in latitude, d(lat). This is because point P is above point O



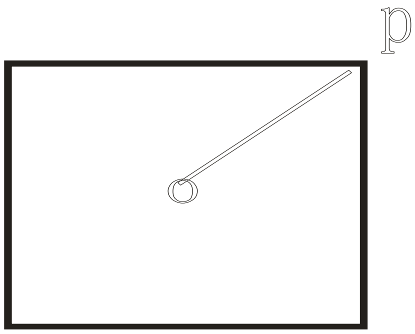


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Figure 11: Longitude of Vertex

Figure 12: Longitude of Point P

Figures 11 and 12 show the pattern followed to move from the reference point to any of the vertex points. Thus the coordinates of the vertices of the square will be obtained as follows, moving from the top right vertex, anti-clockwise;

$\{[\text{lat} + d(\text{lat}),\ \text{lng} + d(\text{lat})], [\text{lat} + d(\text{lat}), \text{lng} - d(\text{lat})], [\text{lat} - d(\text{lat}), \text{lng} - d(\text{lat})], [\text{lat} - d(\text{lat})\ \text{lng} + d(\text{lat})]\}$ (4)

Where;

lat = the reference latitude, **lng** = the reference longitude.

After using this method to obtain the vertices of the squares drawn around each eNB, the same method is also used to obtain the vertices of the squares drawn around each of the already obtained vertices. These are altogether used as test splitter locations.

The distances from each of these test splitter locations to all eNBs including the one at exchange/switch are obtained and summed. To get distance between two points, Vincenty formula and its components shown in equations 5-8 are employed.

$$\text{d}\theta = \tan^{-1}(A|B) \quad (5)$$

$$\text{A} = \sqrt{}((\cos(\text{lat2}).\sin(\text{dlat}))^2 + (\cos(\text{lat1}).\sin(\text{lat2}) - \sin(\text{lat1}.\cos(\text{lat2}).\cos(\text{dlng}))^2 \quad (6)$$

$$\text{B} = (\sin(lat1).\sin(lat2)) + (\cos(lat1).\cos(lat2).\cos(dlng)) \quad (7)$$

$$\text{L} = \text{d}\theta.\text{R}$$

(8)

Where

L = distance between two points, **dθ** = the angle between the two points, **lat1** = latitude of point 1, **lat2** = latitude of point 2, **lng1** = longitude of point 1, **lng2** = longitude of point 2, **dlat** = change in latitude, **dlng** = change in longitude, **R** = mean radius of the earth.

The formulae stated in equations 1-8 are modelled in a MATLAB environment and results as shown in figure 13 was obtained.

III. Results and Discussions

The results generated from this study are divided into manual and the systematic methods. From manual approach, the table 4 shows the detail computation of both great circle and walking distances for splitter location 4.8277864^0N, 7.026582^0E. The walking distances were generated using Google map (two coordinates on map) whereas Great circle distances were generated using GPS VISUALIZER platform (a distance calculator tool for two points in a great circle). Each eNB's great circle distance is obtained from placing the coordinate of that eNB and that of reference coordinate on GPS Visualizer, the reference coordinate is 4.8277864^0N, 7.026582^0E. This is demonstrated in table 4. The cumulative walking distance for all the eNBs with respect to the reference/test splitter coordinate (4.8277864^0N, 7.026582^0E) is given as 577.7 km. Considering the fact that great circle distances may have their greatest challenge of not considering obstructions, it is preferable to take the walking distance length as the minimum length of fiber required for this purpose.

For Systematic approach, The Optimal splitter coordinates as obtained from MATLAB environment are 4.8276, 7.0254. The location is shown in map of figure 13.

Figure 13: Optimal splitter location from Automatic approach

The cumulative distance of 440.240 km which represents the total fiber length was obtained when the coordinates of 4.8276^0N, 7.0254^0E was used as a reference/test splitter location between each eNB. Table 5 shows the detailed breakdown of respective distances between each eNB and test splitter coordinate. Google map was also used to generate walking distances for each eNB- test splitter coordinates.

Table 4: Great Circle and walking distances

EXCHANGE/NODB PARAMETERS					SPLITTER PARAMETERS (1 km from eNB1 to eNB 2)				GREAT CIRCLE DISTANCE (KM)	WALKING DISTANCE (KM)
	LAT1 (Degrees)	LAT1 (Radians)	LONG1 (Degrees)	LONG1 (Radians)	LAT2 (Degrees)	LAT2 (Radians)	LONG2 (Degrees)	LONG2 (Radians)		
exchange	4.808117	0.08392	6.996657	0.12211	4.8277864	0.0842604	7.026582	0.1226363	3.97211	6.2
eNB 1	4.8366	0.08441	7.0286	0.12267	4.827786	0.08426	7.026582	0.122636	1.005203	1.6
eNB 2	4.7737	0.08332	7.0142	0.12242	4.827786	0.08426	7.026582	0.122636	6.16862	10.2
eNB 3	4.7999	0.08377	6.9939	0.12207	4.827786	0.08426	7.026582	0.122636	4.767435	6.1
eNB 4	4.8294	0.08429	7.0919	0.12378	4.827786	0.08426	7.026582	0.122636	7.239448	10
eNB 5	4.7706	0.08326	7.0224	0.12256	4.827786	0.08426	7.026582	0.122636	6.375677	8.1
eNB 6	4.8746	0.08508	6.983	0.12188	4.827786	0.08426	7.026582	0.122636	7.100198	10.1
eNB 7	4.8692	0.08498	7.1137	0.12416	4.827786	0.08426	7.026582	0.122636	10.69458	13.7
eNB 8	4.7196	0.08237	7.1518	0.12482	4.827786	0.08426	7.026582	0.122636	18.36402	23.6
eNB 9	4.8554	0.08474	7.0641	0.12329	4.827786	0.08426	7.026582	0.122636	5.167951	6
eNB 10	4.7909	0.08362	7.1207	0.12428	4.827786	0.08426	7.026582	0.122636	11.20614	14.3
eNB 11	4.7854	0.08352	7.0082	0.12232	4.827786	0.08426	7.026582	0.122636	5.13441	6.4
eNB 12	4.8327	0.08435	7.0685	0.12337	4.827786	0.08426	7.026582	0.122636	4.676523	7.2
eNB 13	4.8039	0.08384	6.9883	0.12197	4.827786	0.08426	7.026582	0.122636	5.00467	6.9
eNB 14	4.8197	0.08412	7.0656	0.12332	4.827786	0.08426	7.026582	0.122636	4.415736	6.7
eNB 15	4.743	0.08278	7.0417	0.1229	4.827786	0.08426	7.026582	0.122636	9.575454	12.6
eNB 16	4.7939	0.08367	7.0308	0.12271	4.827786	0.08426	7.026582	0.122636	3.796858	5.5
eNB 17	4.748	0.08287	7.0989	0.1239	4.827786	0.08426	7.026582	0.122636	11.955	18.9
eNB 18	4.7773	0.08338	7.062	0.12325	4.827786	0.08426	7.026582	0.122636	6.849545	8.2
eNB 19	4.8341	0.08437	6.9845	0.1219	4.827786	0.08426	7.026582	0.122636	4.715218	6
eNB 20	4.8565	0.08476	7.0405	0.12288	4.827786	0.08426	7.026582	0.122636	3.545691	4.9
eNB 21	4.8064	0.08389	7.0424	0.12291	4.827786	0.08426	7.026582	0.122636	2.954143	4.3
eNB 22	4.8146	0.08403	6.9788	0.1218	4.827786	0.08426	7.026582	0.122636	5.493586	7.6
eNB 23	4.8298	0.0843	6.9588	0.12145	4.827786	0.08426	7.026582	0.122636	7.51357	9.3
eNB 24	4.8923	0.08539	6.9143	0.12068	4.827786	0.08426	7.026582	0.122636	14.36035	16.5
eNB 25	4.848	0.08461	7.0492	0.12303	4.827786	0.08426	7.026582	0.122636	3.366318	4
eNB 26	4.8514	0.08467	6.9835	0.12188	4.827786	0.08426	7.026582	0.122636	5.447904	7.7
eNB 27	4.8081	0.08392	6.9967	0.12211	4.827786	0.08426	7.026582	0.122636	3.969176	5.3
eNB 28	4.9028	0.08557	6.999	0.12216	4.827786	0.08426	7.026582	0.122636	8.88327	11.5
eNB 29	4.9789	0.0869	6.9611	0.12149	4.827786	0.08426	7.026582	0.122636	18.30218	23.7
eNB 30	4.9969	0.08721	6.95	0.1213	4.827786	0.08426	7.026582	0.122636	20.62986	24.4
eNB 31	4.9539	0.08646	7.0111	0.12237	4.827786	0.08426	7.026582	0.122636	14.12764	17.3
eNB 32	4.9669	0.08669	6.9869	0.12194	4.827786	0.08426	7.026582	0.122636	16.08126	20.7
eNB 33	4.8289	0.08428	7.0219	0.12255	4.827786	0.08426	7.026582	0.122636	0.533338	1
eNB 34	4.8169	0.08407	7.0112	0.12237	4.827786	0.08426	7.026582	0.122636	2.09048	3.1
eNB 35	4.9317	0.08607	7.0021	0.12221	4.827786	0.08426	7.026582	0.122636	11.86871	14.5
eNB 36	4.8407	0.08449	6.9681	0.12162	4.827786	0.08426	7.026582	0.122636	6.636936	8.3
eNB 37	4.8598	0.08482	6.9792	0.12181	4.827786	0.08426	7.026582	0.122636	6.342878	8.6
eNB 38	4.8469	0.08459	7.0369	0.12282	4.827786	0.08426	7.026582	0.122636	2.413286	3.3
eNB 39	4.8585	0.0848	6.9658	0.12158	4.827786	0.08426	7.026582	0.122636	7.550949	9.1
eNB 40	4.88	0.08517	7.01	0.12235	4.827786	0.08426	7.026582	0.122636	6.089612	8.1
eNB 41	4.8669	0.08494	7.03	0.1227	4.827786	0.08426	7.026582	0.122636	4.36567	7.1
eNB 42	4.8378	0.08444	7.037	0.12282	4.827786	0.08426	7.026582	0.122636	1.603808	2.1
eNB 43	4.8842	0.08525	7.138	0.12458	4.827786	0.08426	7.026582	0.122636	13.84695	17.7
eNB 44	4.7815	0.08345	7.0398	0.12287	4.827786	0.08426	7.026582	0.122636	5.351128	6.3
eNB 45	4.8116	0.08398	6.9561	0.12141	4.827786	0.08426	7.026582	0.122636	8.014217	10.6
eNB 46	4.9011	0.08554	6.9269	0.1209	4.827786	0.08426	7.026582	0.122636	13.72697	17
eNB 47	4.9058	0.08562	6.9066	0.12054	4.827786	0.08426	7.026582	0.122636	15.87325	18.4
eNB 48	4.8024	0.08382	6.944	0.1212	4.827786	0.08426	7.026582	0.122636	9.575779	12.4
eNB 49	4.8354	0.08439	7.0528	0.12309	4.827786	0.08426	7.026582	0.122636	3.025785	4.4
eNB 50	4.7947	0.08368	7.0497	0.12304	4.827786	0.08426	7.026582	0.122636	4.482936	5.9
eNB 51	4.7581	0.08304	7.0119	0.12238	4.827786	0.08426	7.026582	0.122636	7.917683	10
eNB 52	4.8269	0.08424	6.9961	0.1221	4.827786	0.08426	7.026582	0.122636	3.378845	4.7
eNB 53	4.815	0.08404	7.0419	0.1229	4.827786	0.08426	7.026582	0.122636	2.214073	3.3
eNB 54	4.71	0.0822	7.165	0.12505	4.827786	0.08426	7.026582	0.122636	20.16908	25.3
eNB 55	4.8233	0.08418	7.0572	0.12317	4.827786	0.08426	7.026582	0.122636	3.428968	5.8
eNB 56	4.815	0.08404	7.0652	0.12331	4.827786	0.08426	7.026582	0.122636	4.508943	6.7
eNB 57	4.894	0.08542	7.0153	0.12244	4.827786	0.08426	7.026582	0.122636	7.467938	10
eNB 58	4.8626	0.08487	7.0153	0.12244	4.827786	0.08426	7.026582	0.122636	4.067895	6.3
eNB 59	4.8276	0.08426	7.0145	0.12243	4.827786	0.08426	7.026582	0.122636	1.338846	2.2
									440.7447	577.7

Table 5: Great Circle and walking distances for Systematic method

EXCHANGE/NODB PARAMETERS					SPLITTER PARAMETERS (using the authomatic approach)				GREAT CIRCLE DISTANCE (KM)	WALKING DISTANCE (KM)
	LAT1 (Degrees)	LAT1 (Radians)	LONG1 (Degrees)	LONG1 (Radians)	LAT2 (Degrees)	LAT2 (Radians)	LONG2 (Degrees)	LONG2 (Radians)		
exchange	4.808117	0.08392	6.996657	0.12211	4.8276	0.08426	7.0254	0.12262	3.851776	4.8
eNB 1	4.8366	0.08441	7.0286	0.12267	4.8276	0.08426	7.0254	0.12262	1.061707	1.4
eNB 2	4.7737	0.08332	7.0142	0.12242	4.8276	0.08426	7.0254	0.12262	6.120542	7.8
eNB 3	4.7999	0.08377	6.9939	0.12207	4.8276	0.08426	7.0254	0.12262	4.655009	5.6
eNB 4	4.8294	0.08429	7.0919	0.12378	4.8276	0.08426	7.0254	0.12262	7.370938	10.1
eNB 5	4.7706	0.08326	7.0224	0.12256	4.8276	0.08426	7.0254	0.12262	6.346822	7.7
eNB 6	4.8746	0.08508	6.983	0.12188	4.8276	0.08426	7.0254	0.12262	7.027223	9.7
eNB 7	4.8692	0.08498	7.1137	0.12416	4.8276	0.08426	7.0254	0.12262	10.82182	13.8
eNB 8	4.7196	0.08237	7.1518	0.12482	4.8276	0.08426	7.0254	0.12262	18.44975	23.7
eNB 9	4.8554	0.08474	7.0641	0.12329	4.8276	0.08426	7.0254	0.12262	5.285984	6
eNB 10	4.7909	0.08362	7.1207	0.12428	4.8276	0.08426	7.0254	0.12262	11.32068	14.3
eNB 11	4.7854	0.08352	7.0082	0.12232	4.8276	0.08426	7.0254	0.12262	5.064685	5.9
eNB 12	4.8327	0.08435	7.0685	0.12337	4.8276	0.08426	7.0254	0.12262	4.809035	7.3
eNB 13	4.8039	0.08384	6.9883	0.12197	4.8276	0.08426	7.0254	0.12262	4.882963	6.5
eNB 14	4.8197	0.08412	7.0656	0.12332	4.8276	0.08426	7.0254	0.12262	4.539999	7.1
eNB 15	4.743	0.08278	7.0417	0.1229	4.8276	0.08426	7.0254	0.12262	9.578913	12.1
eNB 16	4.7939	0.08367	7.0308	0.12271	4.8276	0.08426	7.0254	0.12262	3.794737	5
eNB 17	4.748	0.08287	7.0989	0.1239	4.8276	0.08426	7.0254	0.12262	12.02797	19
eNB 18	4.7773	0.08338	7.062	0.12326	4.8276	0.08426	7.0254	0.12262	6.908652	8.1
eNB 19	4.8341	0.08437	6.9845	0.1219	4.8276	0.08426	7.0254	0.12262	4.588992	6
eNB 20	4.8565	0.08476	7.0405	0.12288	4.8276	0.08426	7.0254	0.12262	3.622968	4.8
eNB 21	4.8064	0.08389	7.0424	0.12291	4.8276	0.08426	7.0254	0.12262	3.017467	3.8
eNB 22	4.8146	0.08403	6.9788	0.1218	4.8276	0.08426	7.0254	0.12262	5.36188	7.1
eNB 23	4.8298	0.0843	6.9588	0.12145	4.8276	0.08426	7.0254	0.12262	7.383352	8.9
eNB 24	4.8923	0.08539	6.9143	0.12068	4.8276	0.08426	7.0254	0.12262	14.25756	16.5
eNB 25	4.848	0.08461	7.0492	0.12303	4.8276	0.08426	7.0254	0.12262	3.478413	4
eNB 26	4.8514	0.08467	6.9835	0.12189	4.8276	0.08426	7.0254	0.12262	5.343786	7.8
eNB 27	4.8081	0.08392	6.9967	0.12212	4.8276	0.08426	7.0254	0.12262	3.848902	4.8
eNB 28	4.9028	0.08557	6.999	0.12216	4.8276	0.08426	7.0254	0.12262	8.858675	11.2
eNB 29	4.9789	0.0869	6.9611	0.12149	4.8276	0.08426	7.0254	0.12262	18.26983	23.5
eNB 30	4.9969	0.08721	6.95	0.1213	4.8276	0.08426	7.0254	0.12262	20.59538	24.1
eNB 31	4.9539	0.08646	7.0111	0.12237	4.8276	0.08426	7.0254	0.12262	14.133	17
eNB 32	4.9669	0.08669	6.9869	0.12194	4.8276	0.08426	7.0254	0.12262	16.06601	20.4
eNB 33	4.8289	0.08428	7.0219	0.12256	4.8276	0.08426	7.0254	0.12262	0.413866	0.55
eNB 34	4.8169	0.08407	7.0112	0.12237	4.8276	0.08426	7.0254	0.12262	1.97259	2.6
eNB 35	4.9317	0.08607	7.0021	0.12221	4.8276	0.08426	7.0254	0.12262	11.85975	14.3
eNB 36	4.8407	0.08449	6.9681	0.12162	4.8276	0.08426	7.0254	0.12262	6.513767	8.3
eNB 37	4.8598	0.08482	6.9792	0.12181	4.8276	0.08426	7.0254	0.12262	6.246802	8.7
eNB 38	4.8469	0.08459	7.0369	0.12282	4.8276	0.08426	7.0254	0.12262	2.495824	3.1
eNB 39	4.8585	0.0848	6.9658	0.12158	4.8276	0.08426	7.0254	0.12262	7.443959	9.1
eNB 40	4.88	0.08517	7.01	0.12235	4.8276	0.08426	7.0254	0.12262	6.071306	7.8
eNB 41	4.8669	0.08494	7.03	0.1227	4.8276	0.08426	7.0254	0.12262	4.399581	6.9
eNB 42	4.8378	0.08444	7.037	0.12282	4.8276	0.08426	7.0254	0.12262	1.714152	2.2
eNB 43	4.8842	0.08525	7.138	0.12458	4.8276	0.08426	7.0254	0.12262	13.97321	17.8
eNB 44	4.7815	0.08345	7.0398	0.12287	4.8276	0.08426	7.0254	0.12262	5.368672	5.8
eNB 45	4.8116	0.08398	6.9561	0.12141	4.8276	0.08426	7.0254	0.12262	7.881978	10.2
eNB 46	4.9011	0.08554	6.9269	0.1209	4.8276	0.08426	7.0254	0.12262	13.6343	17
eNB 47	4.9058	0.08562	6.9066	0.12054	4.8276	0.08426	7.0254	0.12262	15.77522	18.5
eNB 48	4.8024	0.08382	6.944	0.1212	4.8276	0.08426	7.0254	0.12262	9.444577	12
eNB 49	4.8354	0.08439	7.0528	0.12309	4.8276	0.08426	7.0254	0.12262	3.157376	4.4
eNB 50	4.7947	0.08368	7.0497	0.12304	4.8276	0.08426	7.0254	0.12262	4.542345	5.5
eNB 51	4.7581	0.08304	7.0119	0.12238	4.8276	0.08426	7.0254	0.12262	7.871492	9.5
eNB 52	4.8269	0.08425	6.9961	0.1221	4.8276	0.08426	7.0254	0.12262	3.247388	4.2
eNB 53	4.815	0.08404	7.0419	0.1229	4.8276	0.08426	7.0254	0.12262	2.303337	3.8
eNB 54	4.71	0.08221	7.165	0.12505	4.8276	0.08426	7.0254	0.12262	20.25556	25.4
eNB 55	4.8233	0.08418	7.0572	0.12317	4.8276	0.08426	7.0254	0.12262	3.55576	6.2
eNB 56	4.815	0.08404	7.0652	0.12331	4.8276	0.08426	7.0254	0.12262	4.627112	7.1
eNB 57	4.894	0.08542	7.0153	0.12244	4.8276	0.08426	7.0254	0.12262	7.467662	9.8
eNB 58	4.8626	0.08487	7.0153	0.12244	4.8276	0.08426	7.0254	0.12262	4.049514	6.1
eNB 59	4.8276	0.08426	7.0145	0.12243	4.8276	0.08426	7.0254	0.12262	1.207725	1.8
									440.2402	564.45

As stated in the manual method analysis, walking distances are always preferred when applying the results to real life situations, because they can avoid obstacles. Using the coordinates obtained from the automatic/systematic approach, the total walking distance obtained using the Google map tool is given as 564.45 kilometers.
Comparing the Optimal splitter locations for both methods as shown in table 6 indicates that both methods have similar results for both location and total distance.

Table 6: Comparison of distance obtained from both methods.

METHOD	LOCATION	GREAT CIRCLE DISTANCE	GREAT CIRCLE DISTANCE
MANUAL	4.8277864, 7.026582	440.7447 KM	440.7447 KM
SYSTEMATIC	4.8276, 7.0254	440.2402 KM	440.2402 KM

From table 6, it is shown that the two measurement approaches have a very close value for both great circle and the walking distances. From figure 14, it is evident that the distances between eNBs are relatively close for both systematic and manual approaches. The blues lines in the plot represent Systematic measurements in km whereas red lines depict manual measurements.

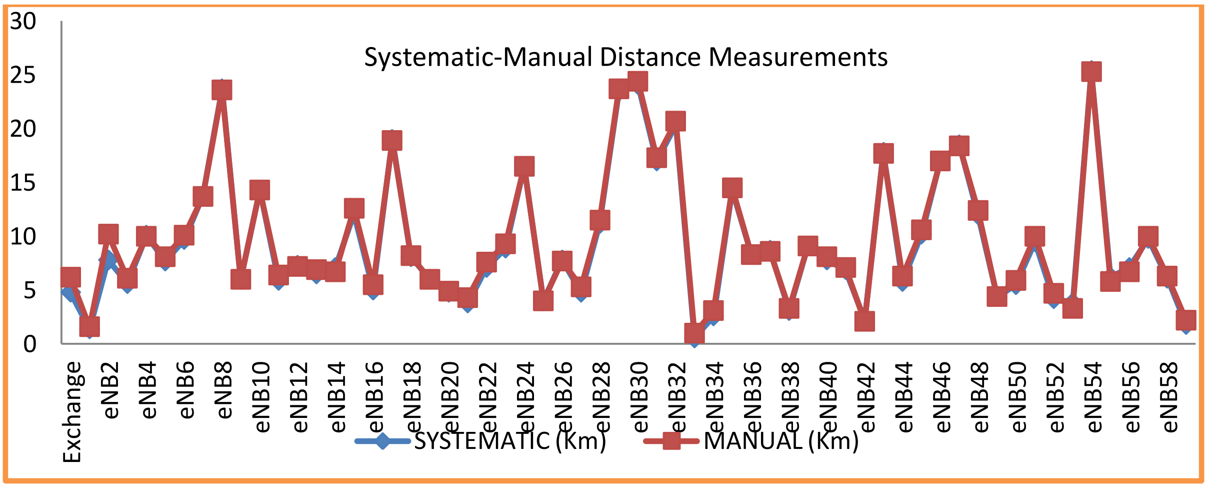

Figure 14: Systematic –Manual Distance measurement model graph

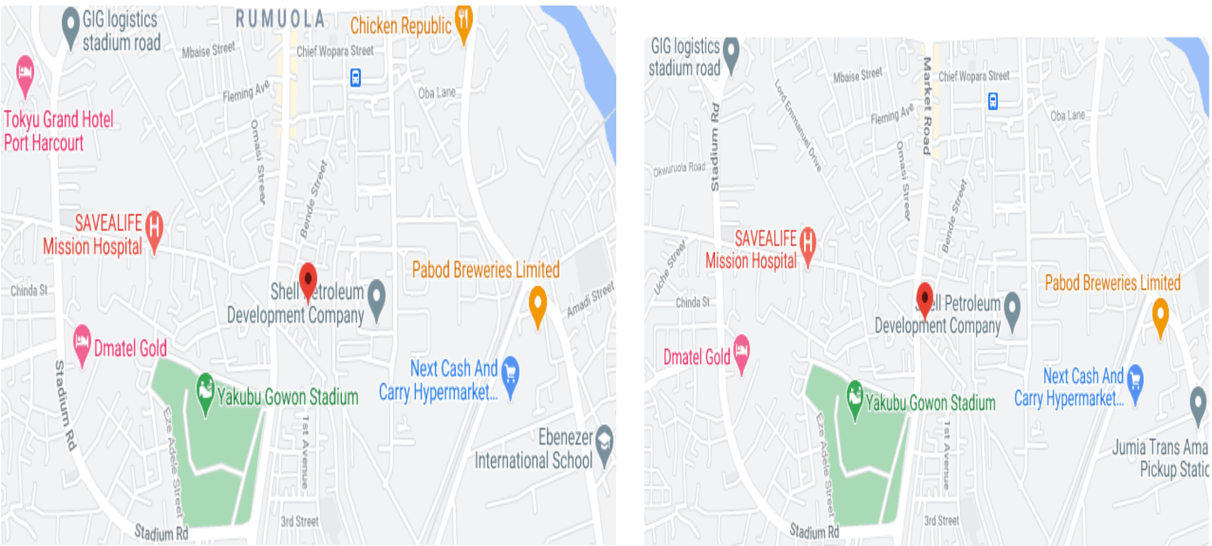

Figure 15: Coordinates for both approaches displaced on a map

Also noticed is that the two approaches gave near coordinates/locations as evidenced in the maps shown in figure 15

IV. Conclusion

This research is concerned with obtaining optimal splitter location for Passive Optical Networks (PON) backhaul and cost-efficient PON deployment. The research aimed at generating optimal location for a PON splitter while taking obstacles into consideration.

The analysis was made based on the (eNB) assets of the Mobile network operators known as Smile Networks. The location chosen for this research was Port-Harcourt city, Rivers State, Nigeria**.** The eNB coordinates were retrieved with the aid of an online tool called Cell Finder. 60 Smile eNB coordinates were used in generating respective eNB distances.

Then, a 1km systematic movement for 35 assumed splitter locations was employed to generate the best location for the splitter that has the least distance between the splitter and the 60 eNBs, which is the manual method. An algorithmic (model) was used to generate the best location for the splitter that has the least distance between the splitter and the 60 eNBs, which is automatic/Systematic method. The research was able to develop two viable methods (Manual and Systematic) of finding optimal splitter coordinates when deploying passive optical networks as a backhaul/access network.

The coordinates so obtained provides shortest distance connecting the eNBs, exchange/Switch and the splitter and would consume less fibre cable, constitute minimal attenuation, considers obstructions, cost efficient and therefore is the optimal location for commissioning the splitter. The findings showed that both Manual and Systematic approaches used are very useful in the determination of optimal splitter location for Passive Optical network deployment in any geographical location. Both approaches showed very similar results.

V. Recommendation

This research has been modeled considering the earth as ellipsoidal in shape, and approximations were made. In light of this, it is recommended that care must be taken in applying this model at regions very near to the poles, as the approximations will have to be altered. It is also recommend that for further analysis of this model, there should be a consideration for incorporating an ability of the model to read data directly from Google map or the likes. This would replace the great circle distance calculations, and hence, the distance approximations would be much closer to reality.

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Okeke R.O, et. al. "Computational Analysis of Optimal Splitter Coordinates for Passive Optical Network (PON) Deployment." *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)* 16(2), (2021): 27-40.