Science and Technology Publishing (SCI & TECH)
ISSN: 2632-1017
Vol. 6 Issue 1, January - 2022

Computation Of Visibility Time For Molniya Orbit Satellites

Enyenihi Henry Johnson[1]
Department of Electrical and Electronic Engineering,
Akwa Ibom State University Mkpat Enin, Akwa Ibom State
enyenihijohnson@aksu.edu.ng

Oto-Obong Chijioke Onwunali[2]
Department of Electrical Electronic and Computer Engineering University of Uyo
Akwa Ibom State, Nigeria

Namnsowo Edet Akpan[2]
Department of Electrical/Electronic Engineering Technology
Akwa Ibom State Polytechnic
Ikot Osurua , Akwa Ibom State
namnsowoakpan@gmail.com

***Abstract*— In this paper, the computation of visibility time for Molniya orbit satellites is presented. Specifically, the study considered 40 Molniya orbit satellites and used their eccentricity and semi-major axis parameters to determine the orbital period and the visibility time as well as the percentage of the visibility time with respect to the orbital period. Notably, the results show that among the 40 satellites considered, the Molniya 1-75 satellite with eccentricity of 0.742 has an orbital period of 16.541 hours and a visibility time of 15.291 hours which is about 92.446 % of the orbital period. Also, the least eccentricity Molniya 1-62 satellite with eccentricity of 0.686 has an orbital period of 16.856 hours and a visibility time of 15.162 hours which is about 89.951 % of the orbital period. It is seen that the percentage of visibility time to the orbital period increases linearly with orbital eccentricity. As such, the higher eccentric orbits are more visible in more portions of their orbital period. Also, the graph plots show that the eccentricity can be used to effectively assess or estimate the visibility of one Molniya orbit satellite relative to another Molniya orbit satellite. However, such estimation cannot be done using the value of the semi-major axis of the Molniya orbit satellites.**

Keywords: Elliptical Orbit, Satellites, Molniya Orbit, Visibility Time, Highly Eccentric Orbit

1. Introduction

Wireless communication technologies has made it easier to access any part of the globe and also to communicate across the globe [1,2,3,4,5,6,7,8,9,10,11]. This is due to advancements in the satellites communication which are also another aspect of the wireless commination via the satellite. The uses of satellite have extended to so many sectors, such as environmental and climate monitoring, early warning system, wireless sensor networks, internet of things applications, smart cities, and other smart systems applications [12,13,14,15,16,17,181,19,20]. In the satellite industry, the highly eccentric elliptical orbit satellites are designed to provide effective coverage for the high –latitude areas, as well as coverage for the polar regions of the globe [21,22,23,24,25,26,27,28,29,30,31,32]. Among the known highly eccentric elliptical orbit satellites, Molniya orbit is the most popular and a good number of satellites operates in the Molniya orbits [33,34,35,36,37]. Particularly, the Molniya range of satellites are mainly of Soviet Union origin designed for communication system and military early warning application [38,39,40,41].
In this paper, the focus is the evaluation of the visibility time of the Molniya range of satellites. The study examines how the visibility times of the Molniya range of satellites relate to eccentricity and the semi-major axis of the orbit. Also, the study will determine the percentage of the orbital period for which the Molniya range of satellites are visible to their target ground stations. The analytical expressions and parameters that are required for the computation of the visibility time and other relevant orbital element values of the Molniya satellites are presented.

2.1 The Visibility Time of a highly eccentric elliptical orbits

The orbital period (T_o) of a satellite is generally given as;

$$T_o = 2\pi\sqrt{\frac{a^3}{\mu}} = 2\pi\sqrt{\frac{a^3}{\mu}} \quad (1)$$

Science and Technology Publishing (SCI & TECH)
ISSN: 2632-1017
Vol. 6 Issue 1, January - 2022

Where the gravitational parameter, μ = 398600 Km^3/s^2 and 'a' is the orbital semi-major axis, and it is defined as,

$$a = \frac{R_a + R_p}{2} \quad \textbf{(2)}$$

Where Rp denotes Radius Of Periapsis and Ra denotes Radius Of Apoapsis.

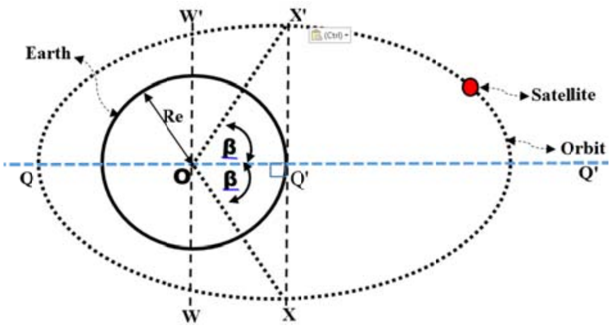

Figure 1 The visibility arc diagram of a satellite with highly eccentric elliptical orbit

When the satellite at latitude, φ the Mean Anomaly denoted as M(φ) is computed in terms of orbital eccentricity, e as follows [42];

$$M(\varphi) = 2\left(\tan^{-1}\left(\sqrt{\frac{(1-e)}{(1+e)}}\right)\right) - \left(e\left(\sqrt{(1-e^2)}\right)\right) \quad (3)$$

For highly elliptical orbit, the ratio (P_φ) of the time interval (Δt_{vHe}) spent by a satellite over a latitude (φ) to the orbital period (T_0) of the satellite is given as [42 ,43];

$$P_\varphi = \frac{\Delta t_{vHe}}{T_0} = 1 - \left[\frac{E_\varphi - e(E_\varphi)}{\pi}\right] \quad (4)$$

Where E_φ denotes the eccentric anomaly given as;

$$E_\varphi = 2\left[\tan^{-1}\left(\sqrt{\frac{(1-e)[\sin(i)+\sin(\varphi)]}{(1+e)[\sin(i)-\sin(\varphi)]}}\right)\right] \quad (5)$$

Where orbit inclination (i) is in radian and the latitude (φ) is in radian. Now the mean anomaly, $M(\varphi)$ is given as;

$$M(\varphi) = E_\varphi - e\left(sin(E_\varphi)\right) \quad (6)$$

$$M(t) = n(t) \quad (7)$$

Where n is the mean motion of the satellite. Hence, at time (t_1) and (t_2), the corresponding $M(t_1)$ and $M(t_2)$ are;

$$M(t_1) = n(t_1) \quad (8)$$

$$M(t_2) = n(t_2) \quad (9)$$

Consequently, considering two points in time, t_1 and t_2, where the satellite passes the latitude (φ) during ascending part of the orbit (at t_1) and descending part of the orbit (at t_2), the change in the mean anomaly is , $M(t_2) - M(t_1)$ and notably, one orbital period amounts to 2π change in the mean anomaly. Hence,

$$\frac{\Delta t_{vHe}}{T_0} = \frac{t_2 - t_1}{T_0} = \frac{2\pi - 2(M(\varphi))}{2\pi} = 1 - \frac{M((\varphi))}{\pi} \quad (10)$$

The visibility time as of highly eccentric orbit, denoted as Δt_{vHe} is expressed as;

$$\Delta t_{vHe} = \left(1 - \frac{M((\varphi))}{\pi}\right) T_o \quad (11)$$

$$\Delta t_{vHe} = \left(1 - \frac{M(\varphi)}{\pi}\right)\left(2\pi\sqrt{\frac{a^3}{\mu}}\right) \quad (12)$$

$$\Delta t_{vHe} = \left(1 - \frac{\left(2\left(\tan^{-1}\left(\sqrt{\frac{(1-e)}{(1+e)}}\right)\right) - \left(e\left(\sqrt{(1-e^2)}\right)\right)\right)}{\pi}\right)\left(2\pi\sqrt{\frac{a^3}{\mu}}\right) \quad (13)$$

3. The case study satellite

The primary case study satellite used in this study is MOLNIYA 1-75 satellite which has eccentricity of 0.69155. The screenshot of a simulated orbital trajectory of MOLNIYA 1-75 satellite using the online platform provided by CelesTrak [44] is shown in Figure 2. The ground footprint and orbital track of the MOLNIYA 1-75 satellite, as captured using n2yo.com satellite tracking tool is shown in Figure 3. Data on some launch details of MOLNIYA 1-75 satellite along with orbital parameters are given in Table 1. In this work, the orbital semi-major axis and eccentricity are used to determine the satellite visibility time.

Table 1 Some MOLNIYA 1-75 satellite launch details along with orbital parameters

LAUNCH DETAILS	
Launched Date	15 February 1989
Category	Molniya
Owner	Commonwealth of Independent States (former USSR)
NORAD ID	19807
CURRENT ORBITAL PARAMETERS	
Inclination	64.132°
Eccentricity	0.69155
RA ascending node	19.678 hr
Argument perihelion	267.647°
Mean anomaly	18.544°
Orbital period	718.161 min
Epoch of osculation	15 Mar 2022, 20:45
DERIVED ORBITAL PARAMETERS	
Min Altitude	1822.9 km
Mean Altitude	20193.9 km
Peak Altitude	38564.9 km

(Source: https://in-the-sky.org/spacecraft.php?id=19807)

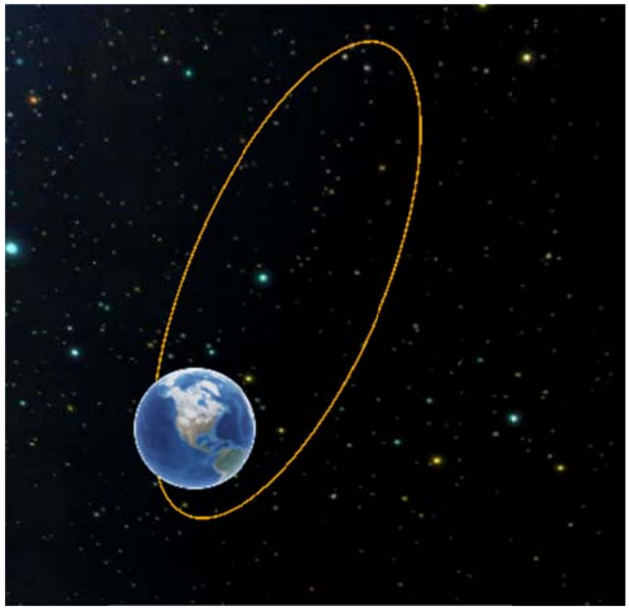

Figure 2 The screenshot of a simulated orbital trajectory of MOLNIYA 1-75 satellite using the online platform provided by CelesTrak [44]

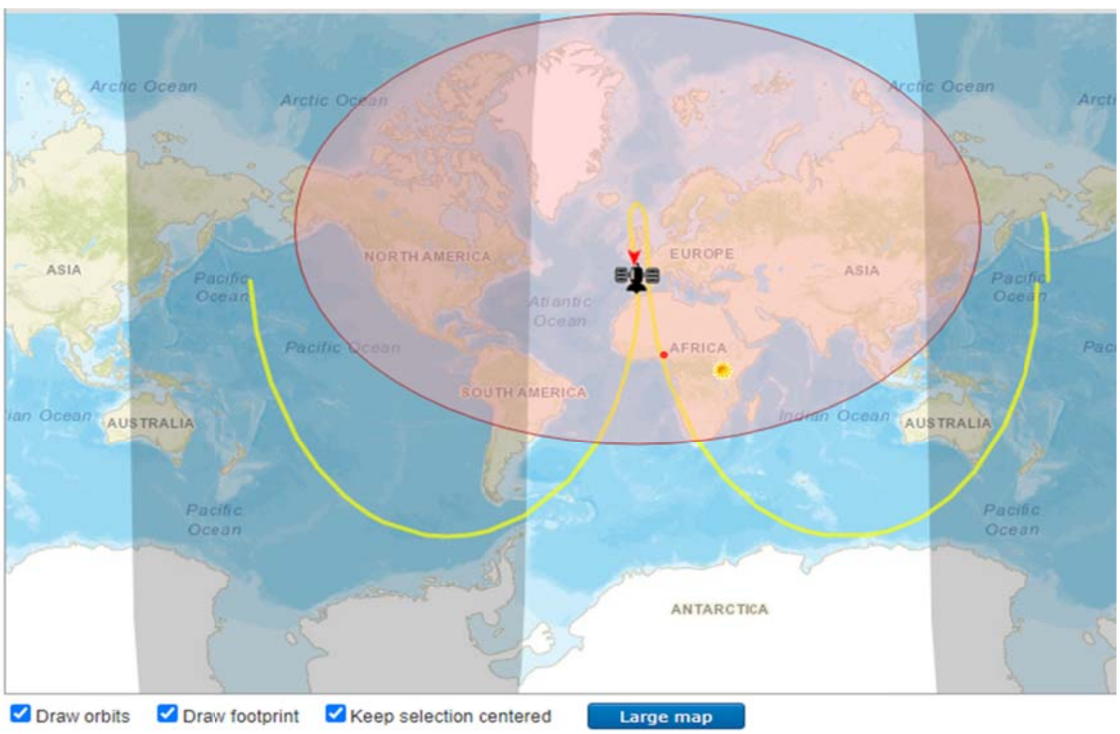

Figure 3: The ground footprint and orbital track of the MOLNIYA 1-75 satellite, as captured using n2yo.com satellite tracking tool is shown in Figure 3. (Source: https://www.n2yo.com/?s=19807)

In addition to the primary case study MOLNIYA 1-75 satellite, another set of 39 MOLNIYA orbit satellites are also considered and their visibility times and associated orbital parameters are compared with those of the primary case study satellite. Hence, a total of 40 different Highly Eccentric Elliptical (HEE) orbit satellites belonging to the MOLNIYA orbit category are considered, as listed in Table 2. The parameters in Table 1 that are required for the visibility computation are the orbital semi-major axis (a) and the orbital eccentricity (e).

Table 2 The key relevant parameters of the 40 different Highly Eccentric Elliptical (HEE) orbit case study satellites belonging to the MOLNIYA category [35]

S/N	Molniya Satellite Number	NORAD ID	Launch date	The semi-major axis, a [km]	The eccentricity, e
1	Molniya 1-75	19 807	2/15/1989	26997.02	0.742
2	Molniya 2-09	7 276	4/26/1974	26640.38	0.737
3	Molniya 2-10	7 376	7/23/1974	26646	0.722
4	Molniya 1-29	7 780	4/29/1975	26574.82	0.743
5	Molniya 2-13	8 015	7/8/1975	26559.84	0.739
6	Molniya 2-14	8 195	9/9/1975	26580.72	0.743
7	Molniya 3-03	8 425	11/14/1975	26576.78	0.742
8	Molniya 1-32	8 601	1/22/1976	26578.61	0.69
9	Molniya 2-17	9 829	2/11/1977	26579.77	0.741
10	Molniya 1-36	9 880	3/24/1977	26579.95	0.742
11	Molniya 3-07	9 941	4/28/1977	26579.66	0.743
12	Molniya 3-08	10 455	10/28/1977	26577.53	0.745
13	Molniya 1-40	10 925	6/2/1978	26573.25	0.744
14	Molniya 3-10	11 057	10/13/1978	26575.27	0.744
15	Molniya 1-44	11 474	7/31/1979	26579.98	0.743
16	Molniya 3-13	11 896	7/18/1980	26574.9	0.743
17	Molniya 1-49	12 156	1/30/1981	26574.08	0.74
18	Molniya 1-52	13 012	12/23/1981	26579.56	0.741
19	Molniya 1-53	13 070	2/26/1982	26579.59	0.742
20	Molniya 3-20	13 875	3/11/1983	26579.5	0.743
21	Molniya 1-56	13 890	3/16/1983	26579.75	0.711
22	Molniya 1-62	15 214	8/24/1984	26571.85	0.686
23	Molniya -63	15 429	12/14/1984	26575.88	0.742
24	Molniya 3-24	15 738	5/29/1985	26579.98	0.74
25	Molniya 3-27	16 393	12/24/1985	26579.97	0.741
26	Molniya 1-69	17 078	11/15/1986	26579.35	0.742
27	Molniya 3-31	17 328	1/22/1987	26575.06	0.742
28	Molniya 1-71	18 946	3/11/1988	26579.7	0.742
29	Molniya 1-80	21 118	2/15/1991	26578.36	0.742
30	Molniya 3-40	21 196	3/22/1991	26576.84	0.738
31	Molniya 1-81	21 426	6/18/1991	26579.59	0.743
32	Molniya 3-41	21 706	9/17/1991	26579.28	0.742
33	Molniya 3-42	22 178	10/14/1992	26573.94	0.742
34	Molniya 1-87	22 949	12/22/1993	26578.37	0.741
35	Molniya 3-47	23 642	8/9/1995	26579.82	0.742
36	Molniya 1-90	24 960	9/24/1997	26571.97	0.743
37	Molniya 1-91	25 485	9/28/1998	26574.82	0.744
38	Molniya 3-50	25 847	7/8/1999	26571.71	0.742
39	Molniya 3-51	26 867	7/20/2001	26576.12	0.743
40	Molniya 1-93	28 163	2/18/2004	26577.93	0.736

3. Results and Discussion

The orbital semi-major axis (Table 2) was used to determine the orbital period for each of the 40 case study satellites while the eccentricity (Table 2) of the orbits are used to compute the mean anomaly for each of the satellites. Then, the mean anomaly and the orbital period were used to determine the visibility time versus eccentricity for the satellites and the results are presented in Table 3 while Figure 4 shows that graph plot for the orbital period and visibility time in hours versus eccentricity. The results of the percentage of visibility time per orbital period versus eccentricity for the 40 case study Molniya satellites are presented in Table 4 while Figure 5 shows that graph plot for the percentage of visibility time per orbital period versus eccentricity.

The results of the orbital period and visibility time in hours versus orbital semi-major axis are presented in Table 5 while Figure 5 shows that graph plot for the orbital period and visibility time in hours versus orbital semi-major axis. The graph plot for the percentage of visibility time per orbital period versus orbital semi-major axis for the 40 case study Molniya satellites is presented in Figure 6.

Notably, the results show that Molniya 1-75 satellite with eccentricity of 0.742 has an orbital period of 16.541 hours and a visibility time of 15.291hours which is about 92.446 % of the orbital period. Also, the least eccentricity Molniya 1-62 satellite with eccentricity of 0.686 has an orbital period of 16.856 hours and a visibility time of 15.162 hours which is about 89.951 % of the orbital period. It is seen that the percentage of visibility time to the orbital period increases linearly with orbital eccentricity. As such, the higher eccentric orbits are more visible in more portions of their orbital period. Also, the graph plots show that the eccentricity can be used to effectively assess or estimate the visibility of one Molniya orbit satellite relative to another Molniya orbit satellite. However, such estimation cannot be done using the value of the semi-major axis of the Molniya orbit satellites.

Table 3 The results of the orbital period and visibility time versus eccentricity for the 40 case study Molniya satellites

S/N	Molniya Satellite Number	Eccentricity, e	Molniya visibility time in hour	Orbital Period, To (hour)	S/N	Molniya Satellite Number	Eccentricity, e	Molniya visibility time in hour
1	Molniya 1-62	0.686	15.162	16.856	21	Molniya 3-31	0.742	15.29103
2	Molniya 1-32	0.690	14.950	16.586	22	Molniya 1-71	0.742	15.28553
3	Molniya 1-56	0.711	15.112	16.590	23	Molniya 1-80	0.742	15.28834
4	Molniya 2-10	0.722	15.144	16.537	24	Molniya 3-41	0.742	15.29119
5	Molniya 1-93	0.736	15.235	16.525	25	Molniya 3-42	0.742	15.29118
6	Molniya 2-09	0.737	15.256	16.541	26	Molniya 3-47	0.742	15.29075
7	Molniya 3-40	0.738	15.261	16.538	27	Molniya 3-50	0.742	15.28776
8	Molniya 2-13	0.739	15.269	16.540	28	Molniya 1-29	0.743	15.29805
9	Molniya 1-49	0.740	15.277	16.540	29	Molniya 2-14	0.743	15.29711
10	Molniya 3-24	0.740	15.277	16.541	30	Molniya 3-07	0.743	15.29606
11	Molniya 2-17	0.741	15.284	16.540	31	Molniya 1-44	0.743	15.29797
12	Molniya 1-52	0.741	15.282	16.539	32	Molniya 3-13	0.743	15.29775
13	Molniya 3-27	0.741	15.279	16.536	33	Molniya 3-20	0.743	15.29404
14	Molniya 1-87	0.741	15.281	16.537	34	Molniya 1-81	0.743	15.29712
15	Molniya 1-75	0.742	15.291	16.541	35	Molniya 1-90	0.743	15.29813
16	Molniya 3-03	0.742	15.288	16.537	36	Molniya 3-51	0.743	15.29267
17	Molniya 1-36	0.742	15.287	16.536	37	Molniya 1-40	0.744	15.30169
18	Molniya 1-53	0.742	15.291	16.540	38	Molniya 3-10	0.744	15.29952
19	Molniya -63	0.742	15.291	16.540	39	Molniya 1-91	0.744	15.3026
20	Molniya 1-69	0.742	15.291	16.540	40	Molniya 3-08	0.745	15.31089

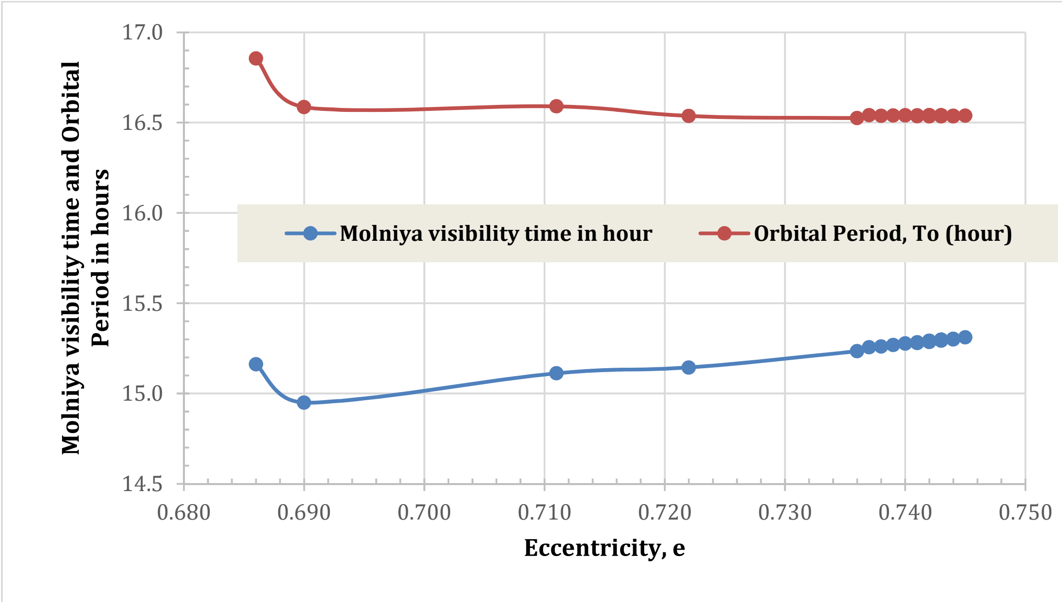

Figure 4 The graph plot for the orbital period and visibility time in hours.

Table 4 The results of the percentage of visibility time per orbital period versus eccentricity for the 40 case study Molniya satellites

S/N	Molniya Satellite Number	Eccentricity, e	Percentage of visibility time per orbital period (%)	S/N	Molniya Satellite Number	Eccentricity, e	Percentage of visibility time per orbital period (%)
1	Molniya 1-62	0.686	89.951	21	Molniya 3-31	0.742	92.44616
2	Molniya 1-32	0.690	90.136	22	Molniya 1-71	0.742	92.44616
3	Molniya 1-56	0.711	91.090	23	Molniya 1-80	0.742	92.44616
4	Molniya 2-10	0.722	91.579	24	Molniya 3-41	0.742	92.44616
5	Molniya 1-93	0.736	92.189	25	Molniya 3-42	0.742	92.44616
6	Molniya 2-09	0.737	92.232	26	Molniya 3-47	0.742	92.44616
7	Molniya 3-40	0.738	92.275	27	Molniya 3-50	0.742	92.44616
8	Molniya 2-13	0.739	92.318	28	Molniya 1-29	0.743	92.4888
9	Molniya 1-49	0.740	92.361	29	Molniya 2-14	0.743	92.4888
10	Molniya 3-24	0.740	92.361	30	Molniya 3-07	0.743	92.4888
11	Molniya 2-17	0.741	92.403	31	Molniya 1-44	0.743	92.4888
12	Molniya 1-52	0.741	92.403	32	Molniya 3-13	0.743	92.4888
13	Molniya 3-27	0.741	92.403	33	Molniya 3-20	0.743	92.4888
14	Molniya 1-87	0.741	92.403	34	Molniya 1-81	0.743	92.4888
15	Molniya 1-75	0.742	92.446	35	Molniya 1-90	0.743	92.4888
16	Molniya 3-03	0.742	92.446	36	Molniya 3-51	0.743	92.4888
17	Molniya 1-36	0.742	92.446	37	Molniya 1-40	0.744	92.53138
18	Molniya 1-53	0.742	92.446	38	Molniya 3-10	0.744	92.53138
19	Molniya -63	0.742	92.446	39	Molniya 1-91	0.744	92.53138
20	Molniya 1-69	0.742	92.446	40	Molniya 3-08	0.745	92.57388

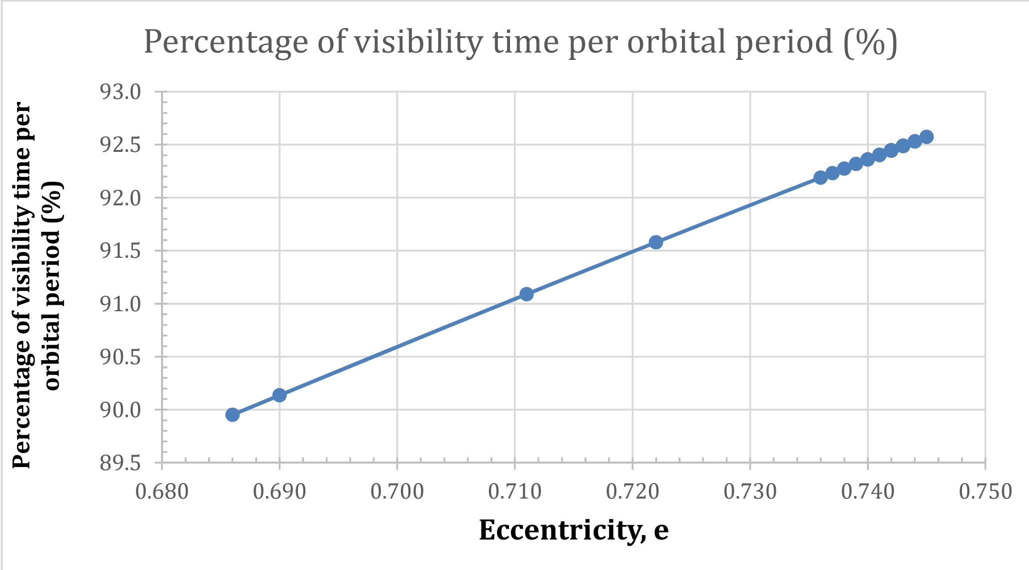

Figure 5 The graph plot for the percentage of visibility time per orbital period versus eccentricity

Table 5 The results of the orbital period and visibility time in hours versus orbital semi-major axis

S/N	Molniya Satellite Number	Orbital Semi-Major Axis, a (km)	Molniya visibility time in hour	Orbital Period, To (hour)	S/N	Molniya Satellite Number	Orbital Semi-Major Axis, a (km)	Molniya visibility time in hour
1	Molniya 1-93	26559.840	15.235	16.525	21	Molniya 2-13	26578.61	15.26901
2	Molniya 3-10	26571.710	15.300	16.534	22	Molniya 3-13	26579.28	15.29775
3	Molniya 1-71	26571.850	15.286	16.535	23	Molniya 3-47	26579.35	15.29075
4	Molniya 3-51	26571.970	15.293	16.535	24	Molniya 1-69	26579.5	15.29085
5	Molniya 3-27	26573.250	15.279	16.536	25	Molniya 1-53	26579.56	15.2909
6	Molniya 3-20	26573.940	15.294	16.536	26	Molniya -63	26579.59	15.29092
7	Molniya 1-36	26574.080	15.287	16.536	27	Molniya 1-44	26579.59	15.29797
8	Molniya 2-10	26574.820	15.144	16.537	28	Molniya 2-17	26579.66	15.2839
9	Molniya 1-40	26574.820	15.302	16.537	29	Molniya 1-29	26579.7	15.29805
10	Molniya 3-03	26574.900	15.288	16.537	30	Molniya 3-31	26579.75	15.29103
11	Molniya 3-50	26575.060	15.288	16.537	31	Molniya 1-49	26579.77	15.2769
12	Molniya 1-87	26575.270	15.281	16.537	32	Molniya 1-90	26579.82	15.29813
13	Molniya 1-80	26575.880	15.288	16.538	33	Molniya 3-24	26579.95	15.27703
14	Molniya 1-91	26576.120	15.303	16.538	34	Molniya 3-42	26579.97	15.29118
15	Molniya 3-40	26576.780	15.261	16.538	35	Molniya 1-75	26579.98	15.29119
16	Molniya 3-07	26576.840	15.296	16.538	36	Molniya 3-41	26579.98	15.29119
17	Molniya 1-52	26577.530	15.282	16.539	37	Molniya 2-09	26580.72	15.25626
18	Molniya 3-08	26577.930	15.311	16.539	38	Molniya 1-32	26640.38	14.95012
19	Molniya 2-14	26578.360	15.297	16.539	39	Molniya 1-56	26646	15.11221
20	Molniya 1-81	26578.370	15.297	16.539	40	Molniya 1-62	26997.02	15.16184

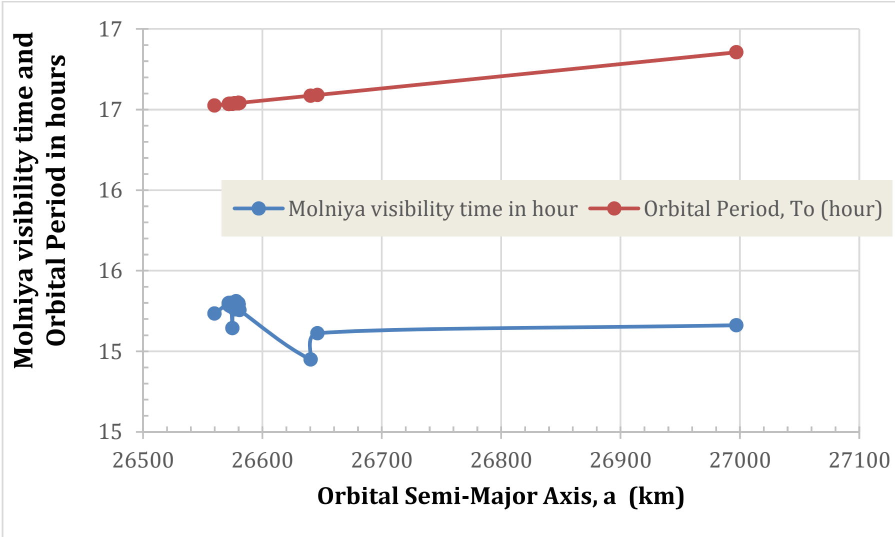

Figure 5 The graph plot for the orbital period and visibility time in hours versus orbital semi-major axis.

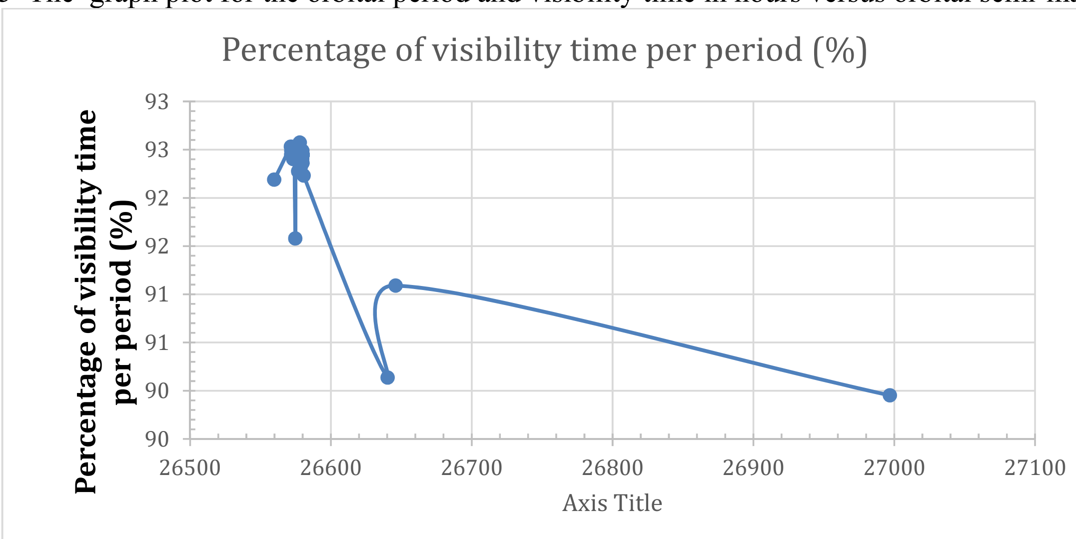

Figure 6 The graph plot for the percentage of visibility time per orbital period versus orbital semi-major axis.

4. Conclusion

The visibility time of highly eccentric elliptical orbit satellite is presented. The study considered 40 MOLNIYA orbit satellites and used their eccentricity and semi-major axis parameters to determine the orbital period and the visibility time as well as the percentage of the visibility time with respect to the orbital period. In all, the results shows that the visibility time of the MOLNIYA orbit satellites can be effectively estimated using the orbital eccentricity.

REFERENCES

1. Rao, S. K., & Prasad, R. (2018). Impact of 5G technologies on industry 4.0. *Wireless personal communications*, *100*(1), 145-159.
2. Johnson, Enyenihi Henry, Simeon Ozuomba, and Ifiok Okon Asuquo. (2019). Determination of Wireless Communication Links Optimal Transmission Range Using Improved Bisection Algorithm. *Universal Journal of Communications and Network, 7(1), 9-20.*
3. Simeon, Ozuomba (2014) "Fixed Point Iteration Computation Of Nominal Mean Motion And Semi Major Axis Of Artificial Satellite Orbiting An Oblate Earth." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 1 Issue 4, November – 2014*
4. Akpakwu, G. A., Silva, B. J., Hancke, G. P., & Abu-Mahfouz, A. M. (2017). A survey on 5G networks for the Internet of Things: Communication technologies and challenges. *IEEE access*, *6*, 3619-3647.

5. Kalu, C., Ozuomba, Simeon. & Udofia, K. (2015). Web-based map mashup application for participatory wireless network signal strength mapping and customer support services. *European Journal of Engineering and Technology, 3 (8)*, 30-43.
6. Simeon, Ozuomba. (2016) "Comparative Analysis Of Rain Attenuation In Satellite Communication Link For Different Polarization Options." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 3 Issue 6, June - 2016*
7. Ahmed, E., Yaqoob, I., Gani, A., Imran, M., & Guizani, M. (2016). Internet-of-things-based smart environments: state of the art, taxonomy, and open research challenges. *IEEE Wireless Communications*, *23*(5), 10-16.
8. Simeon, Ozuomba. (2016) "Comparative Analysis Of Rain Attenuation In Satellite Communication Link For Different Polarization Options." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 3 Issue 6, June – 2016*
9. Zeinab, K. A. M., & Elmustafa, S. A. A. (2017). Internet of things applications, challenges and related future technologies. *World Scientific News*, *67*(2), 126-148.
10. Unwin, P. T. H., & Unwin, T. (2017). *Reclaiming information and communication technologies for development*. Oxford University Press.
11. Simeon, Ozuomba. (2017). "Determination Of The Clear Sky Composite Carrier To Noise Ratio For Ku-Band Digital Video Satellite Link" *Science and Technology Publishing (SCI & TECH) Vol. 1 Issue 7, July – 2017*
12. Ahmed, E., Yaqoob, I., Gani, A., Imran, M., & Guizani, M. (2016). Internet-of-things-based smart environments: state of the art, taxonomy, and open research challenges. *IEEE Wireless Communications*, *23*(5), 10-16.
13. Samuel, Wali, Simeon Ozuomba, and Philip M. Asuquo (2019). EVALUATION OF WIRELESS SENSOR NETWORK CLUSTER HEAD SELECTION FOR DIFFERENT PROPAGATION ENVIRONMENTS BASED ON LEE PATH LOSS MODEL AND K-MEANS ALGORITHM. EVALUATION, 3(11). *Science and Technology Publishing (SCI & TECH) Vol. 3 Issue 11, November - 2019*
14. Shah, S. A., Seker, D. Z., Rathore, M. M., Hameed, S., Yahia, S. B., & Draheim, D. (2019). Towards disaster resilient smart cities: Can internet of things and big data analytics be the game changers?. *IEEE Access*, *7*, 91885-91903.
15. Islam, N., Rashid, M. M., Pasandideh, F., Ray, B., Moore, S., & Kadel, R. (2021). A review of applications and communication technologies for internet of things (Iot) and unmanned aerial vehicle (uav) based sustainable smart farming. *Sustainability*, *13*(4), 1821.
16. Simeon, Ozuomba. (2020). "APPLICATION OF KMEANS CLUSTERING ALGORITHM FOR SELECTION OF RELAY NODES IN WIRELESS SENSOR NETWORK." *International Multilingual Journal of Science and Technology (IMJST) Vol. 5 Issue 6, June – 2020*
17. Njoku, Felix A., Ozuomba Simeon, and Fina Otosi Faithpraise (2019). Development Of Fuzzy Inference System (FIS) For Detection Of Outliers In Data Streams Of Wireless Sensor Networks. *International Multilingual Journal of Science and Technology (IMJST) Vol. 4 Issue 10, October - 2019*
18. Samuel, W., Ozuomba, Simeon, & Constance, K. (2019). SELF-ORGANIZING MAP (SOM) CLUSTERING OF 868 MHZ WIRELESS SENSOR NETWORK NODES BASED ON EGLI PATHLOSS MODEL COMPUTED RECEIVED SIGNAL STRENGTH. *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 6 Issue 12, December - 2019*
19. Jiang, D. (2020). The construction of smart city information system based on the Internet of Things and cloud computing. *Computer Communications*, *150*, 158-166.
20. Simeon, Ozuomba. (2020). "Analysis Of Effective Transmission Range Based On Hata Model For Wireless Sensor Networks In The C-Band And Ku-Band." *Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 12, December - 2020*
21. Trishchenko, A. P., & Garand, L. (2012). Observing polar regions from space: advantages of a satellite system on a highly elliptical orbit versus a constellation of low Earth polar orbiters. *Canadian Journal of Remote Sensing*, *38*(1), 12-24.
22. Trishchenko, A. P., Garand, L., Trichtchenko, L. D., & Nikitina, L. V. (2016). Multiple-apogee highly elliptical orbits for continuous meteorological imaging of polar regions: Challenging the classical 12-h Molniya orbit concept. *Bulletin of the American Meteorological Society*, *97*(1), 19-24.
23. Maral, G., Bousquet, M., & Sun, Z. (2020). *Satellite communications systems: systems, techniques and technology*. John Wiley & Sons.
24. Trishchenko, A. P., Garand, L., & Trichtchenko, L. D. (2019). Observing polar regions from space: Comparison between highly elliptical orbit and medium Earth orbit constellations. *Journal of*

Atmospheric and Oceanic Technology, *36*(8), 1605-1621.

25. Lee, S., Wu, Y., & Mortari, D. (2016). Satellite constellation design for telecommunication in Antarctica. *International Journal of Satellite Communications and Networking*, *34*(6), 725-737.
26. Ma, F., Zhang, X., Li, X., Cheng, J., Guo, F., Hu, J., & Pan, L. (2020). Hybrid constellation design using a genetic algorithm for a LEO-based navigation augmentation system. *GPS Solutions*, *24*(2), 1-14.
27. Fantino, E., Flores, R. M., Di Carlo, M., Di Salvo, A., & Cabot, E. (2017). Geosynchronous inclined orbits for high-latitude communications. *Acta Astronautica*, *140*, 570-582.
28. Reid, T., Walter, T., Blanch, J., & Enge, P. (2016). GNSS Integrity in the Arctic. *NAVIGATION, Journal of the Institute of Navigation*, *63*(4), 467-490.
29. Nassar, R., McLinden, C., Sioris, C. E., McElroy, C. T., Mendonca, J., Tamminen, J., ... & Wunch, D. (2019). The atmospheric imaging mission for northern regions: AIM-North. *Canadian journal of remote sensing*, *45*(3-4), 423-442.
30. Reid, T. G., Walter, T., Enge, P. K., & Sakai, T. (2016). Orbital representations for the next generation of satellite-based augmentation systems. *GPS solutions*, *20*(4), 737-750.
31. Lee, H. W., Jakob, P. C., Ho, K., Shimizu, S., & Yoshikawa, S. (2018). Optimization of satellite constellation deployment strategy considering uncertain areas of interest. *Acta Astronautica*, *153*, 213-228.
32. Pan, L., Zhang, X., Li, X., Li, X., Lu, C., Liu, J., & Wang, Q. (2019). Satellite availability and point positioning accuracy evaluation on a global scale for integration of GPS, GLONASS, BeiDou and Galileo. *Advances in space research*, *63*(9), 2696-2710.
33. Malik, R. A., Jaffer, G., Hassan, I., & Khan, M. Y. (2019). Optimization of a hybrid highly elliptical orbit-based navigation system for continuous high accuracy navigation: An optimum choice for regional navigation. *NAVIGATION, Journal of the Institute of Navigation*, *66*(2), 289-303.
34. Vigneron, A. C., de Ruiter, A. H., Burlton, B. V., & Soh, W. K. (2016). Nonlinear filtering for autonomous navigation of spacecraft in highly elliptical orbit. *Acta Astronautica*, *126*, 138-149.
35. Alessi, E. M., Buzzoni, A., Daquin, J., Carbognani, A., & Tommei, G. (2021). Dynamical properties of the Molniya satellite constellation: Long-term evolution of orbital eccentricity. *Acta Astronautica*, *179*, 659-669.
36. Talu, T., Alessi, E. M., & Tommei, G. (2021). On the Dominant Lunisolar Perturbations for Long-Term Eccentricity Variation: The Case of Molniya Satellite Orbits. *Universe*, *7*(12), 482.
37. Flores, R., Burhani, B. M., & Fantino, E. (2021). A method for accurate and efficient propagation of satellite orbits: A case study for a Molniya orbit. *Alexandria Engineering Journal*, *60*(2), 2661-2676.
38. Talu, T., Alessi, E. M., & Tommei, G. (2020). Investigation on a doubly-averaged model for the Molniya satellites orbits. *arXiv preprint arXiv:2010.15746*..
39. Buzzoni, A., Guichard, J., Altavilla, G., Figer, A., Alessi, E. M., & Tommei, G. (2019, December). Toward a physical characterization of the Soviet/Russian constellation of Molniya satellites. In *First International Orbital Debris Conference, Sugar Land, Texas*.
40. King-Hele, D. G. (1975). The orbital lifetimes of Molniya satellites. *Journal of the British Interplanetary Society*, *28*, 783-796.
41. Zhu, T. L., Zhao, C. Y., Wang, H. B., & Zhang, M. J. (2015). Analysis on the long term orbital evolution of Molniya satellites. *Astrophysics and Space Science*, *357*(2), 1-12.
42. Trishchenko, A. P., Garand, L., & Trichtchenko, L. D. (2011). Three-apogee 16-h highly elliptical orbit as optimal choice for continuous meteorological imaging of polar regions. *Journal of Atmospheric and Oceanic Technology*, *28*(11), 1407-1422.
43. Trichtchenko, L. D., Nikitina, L. V., Trishchenko, A. P., & Garand, L. (2014). Highly elliptical orbits for arctic observations: Assessment of ionizing radiation. *Advances in Space Research*, *54*(11), 2398-2414.
44. CelesTrak Animation of EKS orbit around Earth.gif . Available at: https://celestrak.com/cesium/orbit-viz.php?tle=/NORAD/elements/gp.php?CATNR=19807&satcat=/pub/satcat.txt&orbits=1