Evaluation Of Direct Satellite Communication Capability Of Lora Transceiver

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Abstract— **In this paper, evaluation of capability of LoRa transceiver communications with earth orbiting satellites is studied. In order to determine the capability of LoRa transceiver to transmit directly from earth to the satellite, the slant range from the earth location to the satellite orbit location was determined along with the propagation loss and then link budget analysis was carried out to determine if effective communication is feasible based on the value of the link margin. Numerical computations were performed with the following parameters; f = 868 MHz, Gt = 0 dBi, G/T = -10 dB, BW = 125 KHz, NF =6 dB, Pt = 20 dBm. The computations were performed for the five different spreading factors, SF , SF operated in LoRa transceivers. The results showed that with spreading factor SF7, the LoRa transceiver can communicate effectively with satellite that has altitude of 1524.57 km, while the corresponding values for the other SF values are 2793.68 km for SF8, 4907.22 km for SF 9, 8237.96 km for SF 10, 11364.21 km for SF 11 and 15419.14 Km for SF 12. Also, SF 7 SF 7 can support satellite link with slant range value of 4666 km, while the corresponding values for the other SF values are 6591 km for SF8, 9311 km for SF 9, 13152 km for SF 10, 16557 km for SF 11 and 20844 Km for SF 12. In essence, the LoRa transceiver configurations selected in this study can effectively support direct earth to satellite communication for Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellites with altitudes less than 15,419 Km.**

Keywords— Low Earth Orbit (LEO), LoRa transceiver, Medium Earth Orbit (MEO) communication link, earth orbiting satellites, spreading factors

1. Introduction

In recent years, there has been rapid adoption of Internet of Things (IoT) and smart technologies across the globe [1,2,3,4,5,6,7,8,9]. The IoT and smart technologies rely heavily on sensor nodes and their related technologies. The sensor nodes enables the IoT and smart systems to monitor the environment and then respond accordingly by controlling actuators [11,12,13,14,15,16,17,18,19]. In this wise, sensors are key to monitoring and controlling capabilities of IoT and smart systems. However, the sensor nodes require communication mechanisms to enable it connect with the gateways and server to which it will transmit the data it acquired from the environment. Remarkably, long range (LoRa) communication transceiver technology has been developed for such sensor node applications in IoT and smart systems [20, 21, 22, 23, 24]. Accordingly, today, LoRa transceivers or LoRa technology-based sensor nodes have been widely deployed in many terrestrial IoT and smart system applications. In any case, though the transmission range of LoRa transceivers is quite high when compared with other transceiver technologies, the ability for LoRa transceivers to communicate directly with satellites is still being assessed [25, 26, 27, 28, 29, 30,31,32].

Usually, the effect of various propagation loss mechanisms on the signal limits the transmission range of the wireless link [33,34,35,36,37,338,39,40,41,42,43,44,45]. Accordingly, in this paper, the link budget approach is used to determine the orbital altitude, slant range and propagation loss that can be supported by the LoRa transceiver and still achieve effective communication from earth location to satellite in their orbit [46,47,48,49,50,51,52]. The details of the mathematical analysis are presented. Additionally, numerical computations are also presented based on a given set of LoRa transceiver and communication link parameters dataset. The discussions on the results present the research findings based on the given input dataset.

2. METHODOLOGY

In order to determine the ability of LoRa transceiver to transmit directly from earth to the satellite, the slant range from the earth location to the satellite orbit location must first be determined. Then, the free space propagation loss model is used along with the slant range to determine the expected propagation loss. The link budget analysis is then carried out to determine is the operating carrier to noise ratio satisfies the minimum carrier to noise ratio requirement for effective communication.

Now, the slant range , d for an earth station–satellite link with the satellite's orbit altitude given as $\mathrm{H_s}$, earth radius given as $\mathrm{R_e}$ and elevation angle given as θ_{eL} is calculated with the following expressions [52,53];

$$d = \sqrt{[(\mathrm{R_e} + \mathrm{H_s})^2 + \mathrm{R_e}^2 - 2(\mathrm{R_e})(\mathrm{R_e} + \mathrm{H_s})(\sin(\varphi))]} \quad (1)$$

Where

$$\varphi = \sin\left[\theta_{eL} + \sin^{-1}\left\{\left(\frac{\mathrm{R_e}}{\mathrm{R_e} + \mathrm{H_s}}\right)(\cos(\theta_{eL}))\right\}\right] \quad (2)$$

The propagation loss (L_{pu}) using free space model is calculated as follows;

$$L_{pu} = 32.45 + 20\,\mathrm{og}(f) + 20\mathrm{Log}(d_{sr}) \quad (3)$$

Where frequency (f) is expressed in MHz and d is expressed in km.

The carrier to noise ratio of the satellite uplink, denoted as $C/N|_{up}$ is given as,

$$C/N|_{up} = P_{gtu(dB)} + G_{gu(dB)} + (\mathrm{G_{su}}/\mathrm{T_u}) - L_{pu} - 10(\mathrm{Log}(\mathrm{B_u})) + 228 \quad (4)$$

Where $P_{gtu(dB)}$ is the ground station transmitter power, $G_{gu(dB)}$ is the ground station antenna gain, $\mathrm{G_{su}}$ is the satellite antenna gain, $\mathrm{T_u}$ is the satellite receiver system temperature and $\mathrm{B_u}$ is the link noise bandwidth in Hz.

In LoRa technology, the required carrier to noise ratio, $C/N|_{rqd}$ can be determined from the LoRa transceiver sensitivity ($S_{LoRasens}$), the noise figure (NF) and bandwidth which is the same as $\mathrm{B_u}$ as follows;

$$C/N|_{rqd} = S_{LoRasens} + 174 - 10\,\mathrm{Log_{10}}(\mathrm{B_u}) - NF \quad (5)$$

For the wireless communication link to be feasible, the value of $C/N|_{up}$ must be greater or equal to $C/N|_{up}$. Let the link margin (LM) be defined as

$$LM = \left.\frac{C}{N}\right|_{up} - \left.\frac{C}{N}\right|_{rqd} \quad (6)$$

Hence, the satellite communication link is feasible if $LM \geq 0$ otherwise the link is not feasible. The study in this paper seeks to determine the range of values of satellite link slant range , d and orbit altitude given as $\mathrm{H_s}$ for which the satellite communication link is feasible. The study will consider satellites.

3. Results and discussion

The orbital altitude ranges from values of about 500 km for LEO satellites to vales far above 36,000 km for HEO satellites. The numerical computations were performed with the following parameters; f = 868 MHz, Gt = 0 dBi, G/T = -10 dB, BW = 125 KHz, NF =6 dB, Pt = 20 dBm. The LoRa transceiver Sensitivity ($S_{LoRasens}$) and computed required signal to noise ratio, carrier to noise ratio, $C/N|_{rqd}$ are given in Table 1. The orbital altitudes were selected for each spreading factor from a value of 200 km to an altitude that the link margin is approximately zero (0 dB). The results on the link margin versus orbital altitude of the satellites for the five different spreading factors, SF operated in LoRa transceivers are given in Table 2 , Figure 1 and Figure 2. Similar set of results for the link margin versus slant range are given in Table 3 , Figure 3 and Figure 4. The slant range is computed for elevation angle of zero which gives the largest slant range value for any earth station-satellite link.

The results in Table 2 , Figure 1 and Figure 2 show that SF 7 can communicate effectively with satellite that has altitude of 1524.57 km, while the corresponding values for the other SF values are 2793.68 km for SF8, 4907.22 km for SF 9, 8237.96 km for SF 10, 11364.21 km for SF 11 and 15419.14 Km for SF 12. Also, the results in Table 3 , Figure 3 and Figure 4 show that SF 7 SF 7 can support satellite link with slant range value of 4666 km, while the corresponding values for the other SF values are 6591 km for SF8, 9311 km for SF 9, 13152 km for SF 10, 16557 km for SF 11 and 20844 Km for SF 12. The altitude of 15419.14 Km in for the medium earth orbit satellites. In essence, the LoRa transceiver configurations selected in this study can effectively support direct earth to satellite communication for LEO and MEO satellites with altitudes less than 15,419 Km. Notably, the slant range, the values used are for maximum slant range of the satellite for the given altitude. As such, the LoRa transceiver can still communicate with the satellites at higher than the computed values as long as the elevation angle is greater than 0 degree. The slant range values decreases as elevation increases and it approaches the smallest value as the elevation tends to 90 degrees. In that case, at high elevations, the LoRa transceiver can transmit effectively to satellites with altitudes of about 15,419 km.

Table 1 The data on the LoRa transceiver Sensitivity ($S_{LoRasens}$) and computed required signal to noise ratio, carrier to noise ratio, $C/N|_{rqd}$

	SF 7	SF 8	SF 9	SF 10	SF 11	SF 12
$S_{LoRasens}\ (dBm)$	-124	-127	-130	-133	-135	-137
$C/N|_{rqd}$ (dB)	-7	-10	-13	-16	-18	-20

Table 2 The results on the link margin versus orbital altitude of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers

Orbital Altitude, Hs (km) for SF 7	for SF 7	Orbital Altitude, Hs (km) for SF 8	Link Margin for SF 8	Orbital Altitude, Hs (km) for SF 9	Link Margin for SF 9	Orbital Altitude, Hs (km) for SF 10	Link Margin for SF 10	Orbital Altitude, Hs (km) for SF 11	Link Margin for SF 11	Orbital Altitude, Hs (km) for SF 12	Link Margin for SF 12
200	9.2	200	12.2	200	15.2	200	18.2	200	20.2	200	22.2
270	7.9	342	9.9	450	11.6	630	13.1	800	14.0	1020	14.9
340	6.9	484	8.3	700	9.6	1060	10.7	1400	11.4	1840	12.1
410	6.1	626	7.1	950	8.2	1490	9.1	2000	9.7	2660	10.3
480	5.3	768	6.2	1200	7.1	1920	7.9	2600	8.4	3480	8.9
550	4.7	910	5.4	1450	6.2	2350	6.9	3200	7.3	4300	7.7
620	4.2	1052	4.8	1700	5.5	2780	6.0	3800	6.4	5120	6.8
690	3.7	1194	4.2	1950	4.8	3210	5.3	4400	5.6	5940	5.9
760	3.3	1336	3.6	2200	4.2	3640	4.6	5000	4.9	6760	5.2
830	2.9	1478	3.1	2450	3.7	4070	4.0	5600	4.3	7580	4.5
900	2.5	1620	2.7	2700	3.2	4500	3.5	6200	3.7	8400	3.9
970	2.1	1762	2.3	2950	2.7	4930	3.0	6800	3.1	9220	3.3
1040	1.8	1904	1.9	3200	2.3	5360	2.5	7400	2.6	10040	2.8
1110	1.5	2046	1.6	3450	1.9	5790	2.1	8000	2.2	10860	2.3
1180	1.2	2188	1.2	3700	1.5	6220	1.7	8600	1.7	11680	1.8
1250	0.9	2330	0.9	3950	1.2	6650	1.3	9200	1.3	12500	1.4
1320	0.7	2472	0.6	4200	0.9	7080	0.9	9800	0.9	13320	1.0
1390	0.4	2614	0.3	4450	0.5	7510	0.6	10400	0.6	14140	0.6
1460	0.2	2756	0.1	4700	0.2	7940	0.2	11000	0.2	14960	0.2
1524.57	**0.0**	**2793.68**	**0.0**	**4907.22**	**0.0**	**8237.96**	**0.0**	**11364.21**	**0.0**	**15419.14**	**0.0**

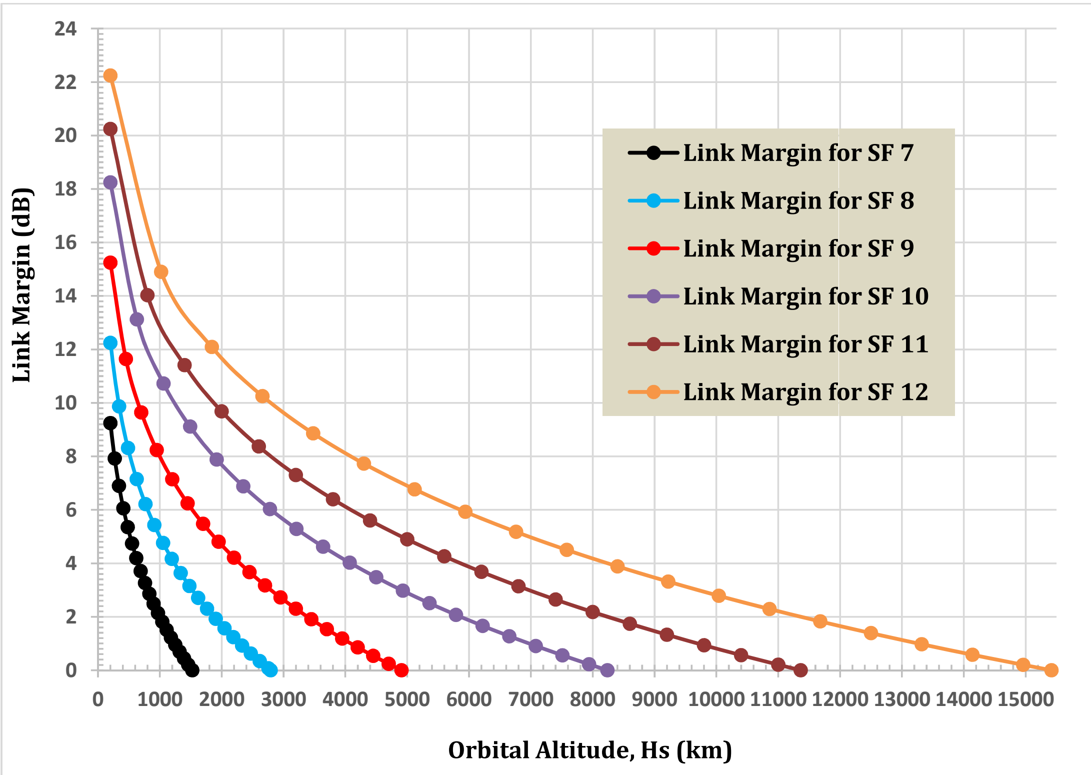

Figure 1 The graph of the link margin versus orbital altitude of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers.

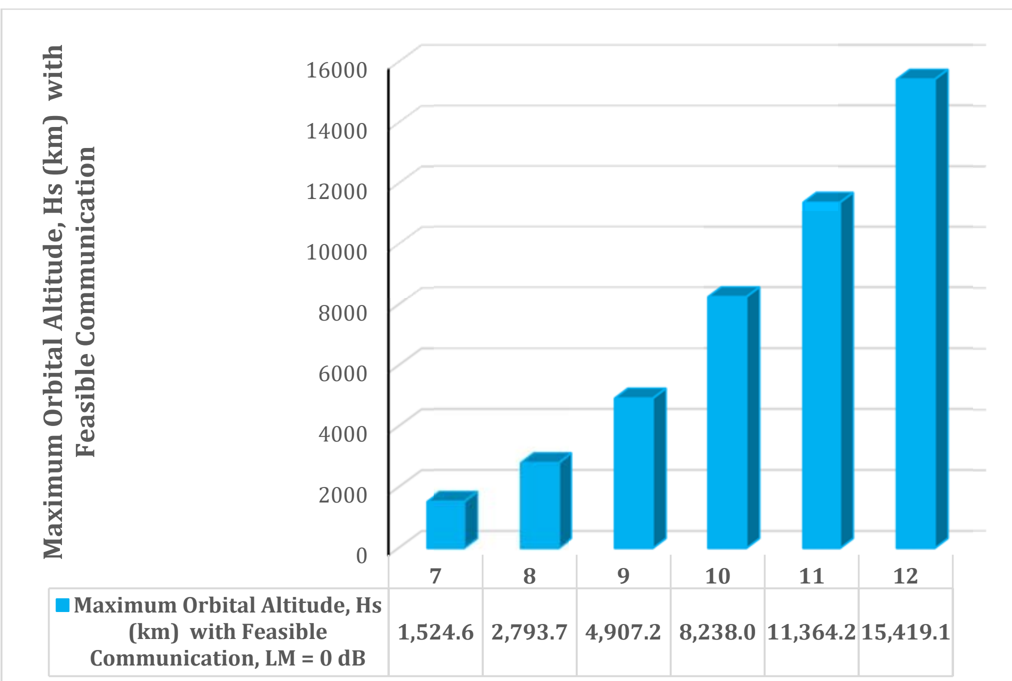

Figure 2 The bar chart of the maximum orbital altitude of the satellites with feasible network communication for the five different spreading factors, SF , SF operated in LoRa transceivers

Table 3 The results on the link margin versus slant range of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers

Slant Range, dsr (km) for SF 7	Link Margin for SF 7	Slant Range, dsr (km) for SF 8	Link Margin for SF 8	Slant Range, dsr (km) for SF 9	Link Margin for SF 9	Slant Range, dsr (km) for SF 10	Link Margin for SF 10	Slant Range, dsr (km) for SF 11	Link Margin for SF 11	Slant Range, dsr (km) for SF 12	Link Margin for SF 12
1610	9.2	1610	12.2	1610	15.2	1610	18.2	1610	20.2	1610	22.2
1875	7.9	2117	9.9	2438	11.6	2904	13.1	3293	14.0	3749	14.9
2110	6.9	2531	8.3	3069	9.6	3827	10.7	4452	11.4	5182	12.1
2323	6.1	2894	7.1	3608	8.2	4607	9.1	5433	9.7	6404	10.3
2521	5.3	3223	6.2	4092	7.1	5308	7.9	6319	8.4	7517	8.9
2705	4.7	3527	5.4	4539	6.2	5958	6.9	7146	7.3	8564	7.7
2880	4.2	3811	4.8	4957	5.5	6572	6.0	7932	6.4	9567	6.8
3046	3.7	4081	4.2	5355	4.8	7159	5.3	8688	5.6	10538	5.9
3205	3.3	4339	3.6	5736	4.2	7725	4.6	9422	4.9	11486	5.2
3358	2.9	4587	3.1	6104	3.7	8275	4.0	10139	4.3	12416	4.5
3506	2.5	4826	2.7	6460	3.2	8812	3.5	10841	3.7	13331	3.9
3649	2.1	5058	2.3	6807	2.7	9338	3.0	11532	3.1	14235	3.3
3788	1.8	5283	1.9	7146	2.3	9854	2.5	12213	2.6	15129	2.8
3923	1.5	5503	1.6	7477	1.9	10363	2.1	12886	2.2	16015	2.3
4055	1.2	5718	1.2	7803	1.5	10864	1.7	13552	1.7	16894	1.8
4184	0.9	5929	0.9	8123	1.2	11360	1.3	14213	1.3	17768	1.4
4311	0.7	6135	0.6	8439	0.9	11851	0.9	14868	0.9	18637	1.0
4434	0.4	6339	0.3	8750	0.5	12337	0.6	15519	0.6	19502	0.6
4556	0.2	6538	0.1	9058	0.2	12819	0.2	16165	0.2	20363	0.2
4666	0.0	6591	0.0	9311	0.0	13152	0.0	16557	0.0	20844	0.0

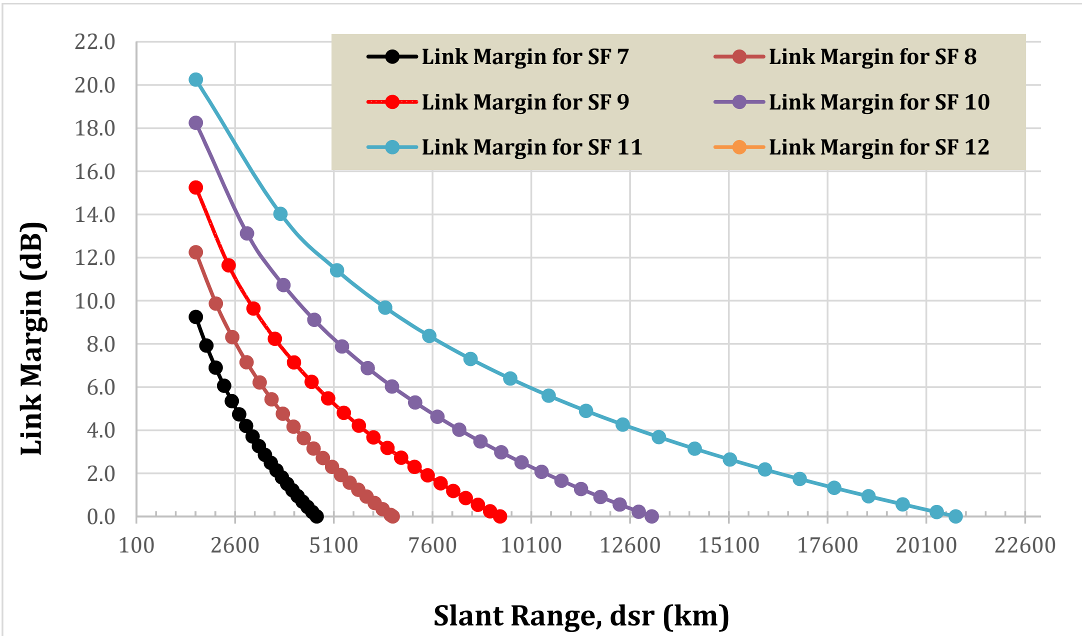

Figure 3 The graph of the link margin versus slant range of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers.

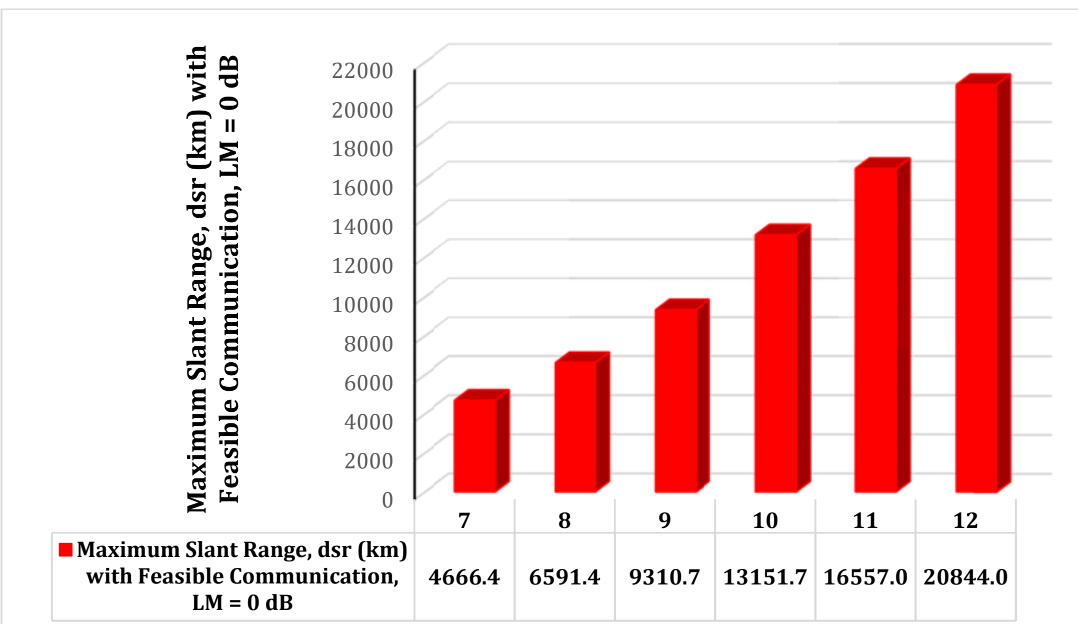

Figure 4 The bar chart of the maximum slant range of the satellites with feasible network communication for the five different spreading factors, SF , SF operated in LoRa transceivers

The results on the propagation loss versus orbital altitude of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers are given in Table 4 , Figure 5 and Figure 6. The results in Table 4 , Figure 5 and Figure 6 show that SF 7 can support satellite link with propagation loss value of 164.6 dB,, while the corresponding values for the other SF values are 167.6 dB for SF8, 170.6 dB for SF 9, 173.6 dB for SF 10, 175.6 dB for SF 11 and 177.6 dB for SF 12. Again, the propagation losses are based on the maximum slant range values. In essence, the propagation losses can be significantly lower than the computed values in Table 4 , Figure 5 and Figure 6 is higher elevation angle values are considered.

In all, the ability of LoRa transceiver to support direct earth station-satellite communication has been established and the maximum orbital altitude accommodated by the selected LoRa transceiver and link parameters are also determined. Specifically, in this paper, the given input specification can support communication with satellites in the LEO and MEO orbit categories.

Table 4 The results on the propagation loss versus orbital altitude of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers

Orbital Altitude, Hs (km) for SF 7	Propagation Loss , Lpu (dB) for SF 7	Orbital Altitude, Hs (km) for SF 8	Propagation Loss , Lpu (dB) for SF 8	Orbital Altitude, Hs (km) for SF 9	Propagation Loss , Lpu (dB) for SF 9	Orbital Altitude, Hs (km) for SF 10	Propagation Loss , Lpu (dB) for SF 10	Orbital Altitude, Hs (km) for SF 11	Propagation Loss , Lpu (dB) for SF 11	Orbital Altitude, Hs (km) for SF 12	Propagation Loss , Lpu (dB) for SF 12
200	155.4	200	155.4	200	155.4	200	155.4	200	155.4	200	155.4
270	156.7	342	157.7	450	159.0	630	160.5	800	161.6	1020	162.7
340	157.7	484	159.3	700	161.0	1060	162.9	1400	164.2	1840	165.5
410	158.5	626	160.5	950	162.4	1490	164.5	2000	165.9	2660	167.3
480	159.3	768	161.4	1200	163.5	1920	165.7	2600	167.2	3480	168.7
550	159.9	910	162.2	1450	164.4	2350	166.7	3200	168.3	4300	169.9
620	160.4	1052	162.8	1700	165.1	2780	167.6	3800	169.2	5120	170.8
690	160.9	1194	163.4	1950	165.8	3210	168.3	4400	170.0	5940	171.7
760	161.3	1336	164.0	2200	166.4	3640	169.0	5000	170.7	6760	172.4
830	161.7	1478	164.5	2450	166.9	4070	169.6	5600	171.3	7580	173.1
900	162.1	1620	164.9	2700	167.4	4500	170.1	6200	171.9	8400	173.7
970	162.5	1762	165.3	2950	167.9	4930	170.6	6800	172.5	9220	174.3
1040	162.8	1904	165.7	3200	168.3	5360	171.1	7400	173.0	10040	174.8
1110	163.1	2046	166.0	3450	168.7	5790	171.5	8000	173.4	10860	175.3
1180	163.4	2188	166.4	3700	169.1	6220	171.9	8600	173.9	11680	175.8
1250	163.7	2330	166.7	3950	169.4	6650	172.3	9200	174.3	12500	176.2
1320	163.9	2472	167.0	4200	169.7	7080	172.7	9800	174.7	13320	176.6
1390	164.2	2614	167.3	4450	170.1	7510	173.0	10400	175.0	14140	177.0
1460	164.4	2756	167.5	4700	170.4	7940	173.4	11000	175.4	14960	177.4
1524.6	164.6	2793.7	167.6	4907.2	170.6	8238.0	173.6	11364.2	175.6	15419.1	177.6

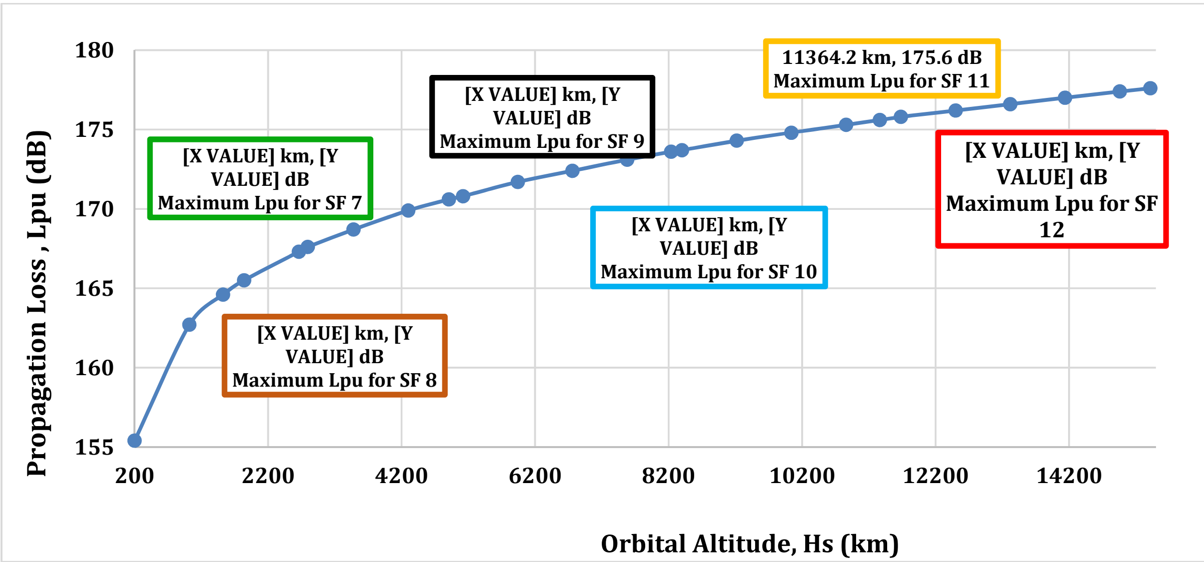

Figure 5 The graph of the propagation loss versus orbital altitude of the satellites for the five different spreading factors, SF , SF operated in LoRa transceivers.

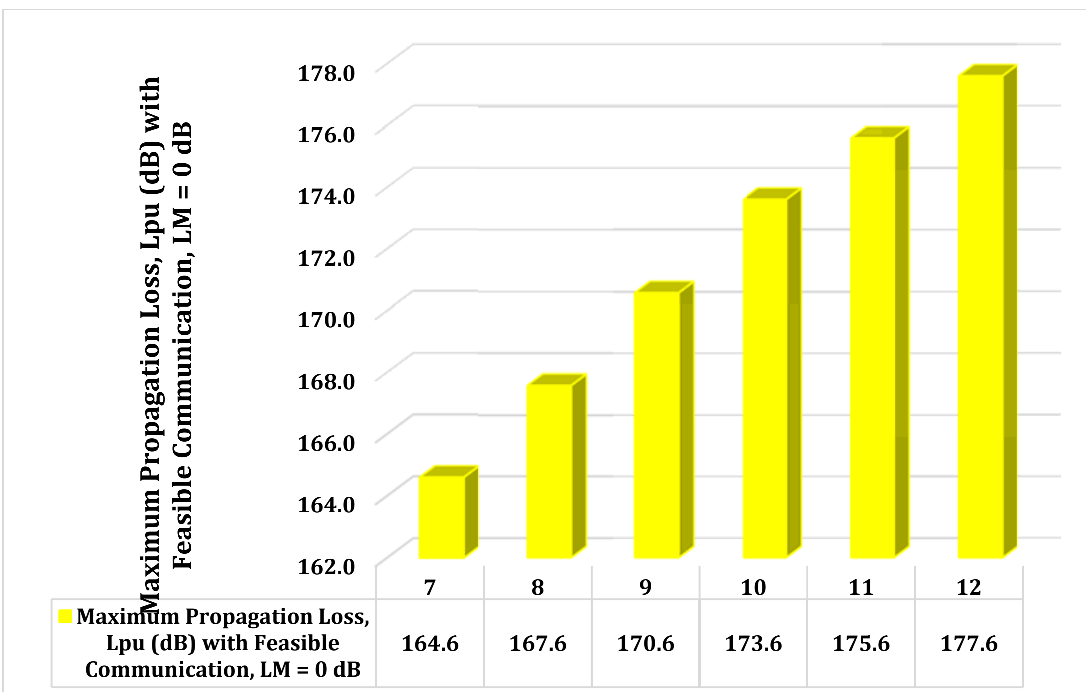

Figure 6 The bar chart of the maximum propagation loss supported for the satellite link with feasible network communication for the five different spreading factors, SF , SF , SF operated in LoRa transceivers

4. Conclusion

The ability of LoRa transceiver to communicate directly with satellite is studied. The study determined the maximum slant range, the propagation loss and the link margin achievable when LoRa transceiver communicates directly with satellites in their orbit. The computation also considered the maximum orbital altitude of the LoRa transceiver can communicate with. The computation were conducted for the five different spreading factors implemented in LoRa transceivers. The study showed that the selected LoRa transceiver and link data can support effective communication with satellites in the LEO and MEO orbit categories.

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