Comparison Of Transmission Range Of Lora Transceiver Deployed In Terrestrial And Satellite Communication Links Operating In Some Selected Industrial, Scientific And Medical Frequency Bands

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***Abstract*— In this paper, comparison of transmission range of LoRa transceiver for terrestrial and satellite communication links operating in selected industrial, scientific and medical (ISM) frequency bands is presented. The transmission range is obtained via the link budget equation. The free space path loss model was used for the satellite link while Hata model was used for the terrestrial link. The study presented some numerical computations using frequencies of 433 MHz, 868 MHz and 2.4 GHz, transmitter power of 20 dBm, transmitter antenna gain of 2 dBi and receiver antenna gain of 10 dBi were used. The spreading factors of 7 to 12 were also considered. The results show that the higher the spreading factor, the more path loss the LoRa transceiver can withstand and still effectively. While a path loss of about 156 dB can be accommodated with spreading factor of 7, path loss of about 169 dB can be accommodated with spreading factor of 12. Also, for the satellite link a maximum path length of about 3,694 km can be attained with spreading factor of 7 and frequency of 433 MHz but a maximum path length of about 15,524 km can be attained with spreading factor of 12 and frequency of 433 MHz. On the other hand, while a maximum path length of about 666 km can be attained with spreading factor of 7 and frequency of 2.4 GHz, a maximum path length of about 2,800 km can be attained with spreading factor of 12 and frequency of 2.4 GHz. For the terrestrial link a maximum path length of 13.5 km can be attained with spreading factor of 7 and frequency of 433 MHz while a maximum path length of about 31.5 km can be attained with spreading factor of 12 and frequency of 433 MHz. On the other hand, while a maximum path length of about 3.7 km can be attained with spreading factor of 7 and for the frequency of 2.4 GHz, a maximum path length of about 8.4 km can be attained with spreading factor of 12 and frequency of 2.4 GHz. Notably, at spreading factor of 7 maximum path length with free space model is about 275 times the value attained with the Hata path loss model applied in large city. Again, at spreading factor of 12 maximum path length with free space model is about 494 times the value attained with the Hata path loss model applied in large city.**

Keywords*— *Transmission Range, LoRa, Terrestrial Communication Link, Industrial, Scientific and Medical (ISM) Frequency Bands, Satellite Communication Links

I. INTRODUCTION

Today wireless sensor network have gain attention of researchers globally due of their usefulness in the evolving Internet of Things (IoT) and smart systems applications [1,2]. Sensor networks rely on low power long range transceiver technologies of which LoRa transceivers have gained popularity among sensor network designers [3,4,5,6,7]. In any case, the attainable transmission range of wireless sensors depends on the specific application and the parameter configurations employed in the specific deployment [8,9]. Accordingly, in this paper, the focus is to ascertain the transmission range attainable by LoRa transceiver deployed in terrestrial communication and the one deployed in direct earth-to-satellite communication link.

Notably, among other factors, the transmission range is impacted by the propagation loss experienced by the signal in the propagation path [10,11]. In direct earth-to-satellite communication link the free space path loss is used to determine the propagation loss [12] and the transmission range whereas in the terrestrial different propagation loss models a can be used depending on the nature of the propagation environment. For city, sub-urban and rural environment, the Hata path loss model can be used whereas for vegetation covered areas, foliage path loss models are employed [13].

Specifically, the study in this paper seek to compare the transmission range attainable while using the free space path loss model for the satellite link and Hata model for the terrestrial link. The study will explain why it is possible to establish direct LoRa sensor node to satellite communication despite the low power and antenna gain of LoRa transceiver. Sample numerical solutions are presented and used to discuss the results

II. METHODOLOGY

This paper seeks to compare the transmission range attainable with LoRa transceiver deployed in terrestrial and satellite applications. Basically, in satellite application, the propagation loss model applied is the free space path loss whereas in the terrestrial applications some empirical path loss models can be used depending on the specific application. For instance, for smart city applications, Hata model can be used whereas for smart agriculture application foliage model like Weissberger model [14] can be used.

Generally, the transmission range is obtained via the link budget equation. Now, consider a LoRa transceiver with transmitter power (P_{txLr}), transmitter antenna gain, (G_{tLr}), spreading factor (SF), bandwidth, (BW), receiver sensitivity (S_{tLr}), noise figure (NF_{Lr} with typical value of 6 dBm) and communicating in a wireless link with signal frequency (f) in MHz, over a distance (d_{tLr}) with receiver antenna gain (G_r), propagation loss (PL_{tink}) and link noise temperature (T_{syst}), the noise power (N_{link}), the received signal strength, (P_{rxLr}) re and link margin (LMG) are given as;

$$P_{rxLr} = P_{txLr} + G_{tLr} + G_r - PL_{tink} \quad (1)$$

$$P_{rxLr} = S_{tLr} - \text{LMG} \quad (2)$$

$$S_{tLr} - \text{LMG} = P_{txLr} + G_{tLr} + G_r - PL_{tink} \quad (3)$$

At maximum transmission range, $d_{tLr(max)}$, LMG = 0, hence, $P_{rxLr} = S_{tLr}$ which gives maximum propagation loss, $PL_{tink(max)}$ expressed as follows;

$$S_{tLr} = P_{txLr} + G_{tLr} + G_r - PL_{tink} \quad (4)$$

$$PL_{tink(max)} = P_{txLr} + G_{tLr} + G_r - S_{tLr} \quad (5)$$

For satellite links, free space path loss model is used to estimate the propagation loss. The path loss by free space model, PL_{FSPL} is expressed as;

$$PL_{FSPL} = 20\log(d_{FSPL}) + 20\log(f) + 32.45 \quad (6)$$

where f is in MHz and d_{FSPL} is in km. Then, the maximum transmission range attainable with LoRa operating in with free space path loss, $d_{FSPL(max)}$ is given as;

$$d_{FSPL(max)} = 10^{\frac{P_{txLr} + G_{tLr} + G_r - S_{tLr} - 20\log(f) - 32.45}{20}} \quad (7)$$

On the other hand, for terrestrial wireless link, Hata model can be used. Now, the path loss by Hata model, PL_{Hata} is expressed as;

$$PL_{Hata} = A + B\log(d_{Hata}) - K \quad (9)$$

where d_{Hata} is in km.

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (10)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (11)$$

$$K = \begin{cases} 0 & Urban\ region \\ 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 & Suburban\ \text{region} \\ 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) & \text{Rural region} \end{cases} \quad (12)$$

$$a(h_m) = \begin{cases} [1.1 * \log_{10} f - 0.7] * h_m - [1.56 * \log_{10} f - 0.8] & for\ \text{small city, open l area} \\ 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 & for\ large\ city\ \text{f} \leq \text{200MHz} \\ 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 & for\ large\ city\ \text{f} \geq \text{400MHz} \end{cases} \quad (13)$$

f is frequency given in MHz and 150 MHz ≤ f≤ 1000MHz; 30m ≤h_b ≤ 200m ;1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km. Then, the maximum transmission range attainable with LoRa operating in with Hata path loss, $d_{Hata(max)}$ is given as;

$$d_{Hata(max)} = 10^{\frac{P_{txLr} + G_{tLr} + G_r - S_{tLr} - A + K}{B}} \quad (14)$$

For the satellite link, for any slant range, d_{Sat} and elevation angle ε_{sat} with earth radius, R_{Earth} , the orbital radius R_{Sat} and orbital altitude H_{Sat} can be determined as follows;

$$R_{Sat} = \sqrt{\left({R_{Earth}}^2 + {d_{Sat}}^2 - [2(R_{Sat})(d_{Sat})(Cos(90 + \varepsilon_{sat}°))]\right)} \quad (15)$$

$$H_{Sat} = R_{Sat} - R_{Earth} \quad (16)$$

where R_{Earth} = 6378 km.

III. RESULTS AND DISCUSSION

The study presented some numerical computations using frequencies of 433 MHz, 868 MHz and 2.4 GHz. The transmitter power of 20 dBm, transmitter antenna gain of 2 dBi and receiver antenna gain of 10 dBi were used. The spreading factors of 7 to 12 were also considered. The receiver sensitivity of LoRa transceiver for the various spreading factors used in the study are shown in Figure 1. The maximum path loss for the link based on the receiver sensitivity of LoRa for the given spreading factor is given in Figure 2. It can be deduced from Equation 5 that the maximum path loss that can be effectively accommodated for a feasible wireless communication with the LoRa transceiver is a function of the receiver sensitivity. As such the results in Figure 2 show that the higher the spreading factor, the more path loss the LoRa transceiver can withstand and still effectively. While a path loss of about 156 dB can be accommodated with spreading factor of 7, path loss of about 169 dB can be accommodated with spreading factor of 12.

The results of the maximum path length versus spreading factor and frequency are shown in Figure 3 for free space path loss model. The results showed that the maximum path length increases with spreading factor and decreases with increase in frequency. While a maximum path length of about 3,694 km can be attained with spreading factor of 7 and for the frequency of 433 MHz, a maximum path length of about 15,524 km can be attained with spreading factor of 12 and frequency of 433 MHz. On the other hand, while a maximum path length of about 666 km can be attained with spreading factor of 7 and for the frequency of 2.4 GHz, a maximum path length of about 2,800 km can be attained with spreading factor of 12 and frequency of 2.4 GHz.

The results of the maximum path length versus spreading factor and frequency are shown in Figure 4 for Hata path loss model applied in large city. The results showed that the maximum path length increases with spreading factor and decreases with increase in frequency. While a maximum path length of about 13.5 km can be attained with spreading factor of 7 and frequency of 433 MHz, a maximum path length of about 31.5 km can be attained with spreading factor of 12 and frequency of 433 MHz. On the other hand, while a maximum path length of about 3.7 km can be attained with spreading factor of 7 and for the frequency of 2.4 GHz, a maximum path length of about 8.4 km can be attained with spreading factor of 12 and frequency of 2.4 GHz.

The results of the comparison of the maximum path length versus spreading factor for free space path loss and Hata path loss model applied in large city at the frequency of 433 MHz are shown in Figure 5. The results show that the maximum attainable path length with free space model is several times higher than that attained with Hata model. Notably, at spreading factor of 7 maximum path length with free space model is about 275 times the value attained with the Hata path loss model applied in large city. Again, at spreading factor of 12 maximum path length with free space model is about 494 times the value attained with the Hata path loss model applied in large city.

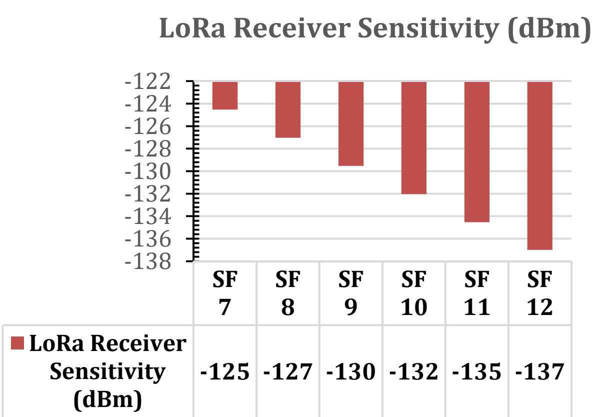

Figure 1 The receiver sensitivity of LoRa transceiver for the various spreading factors used in the study

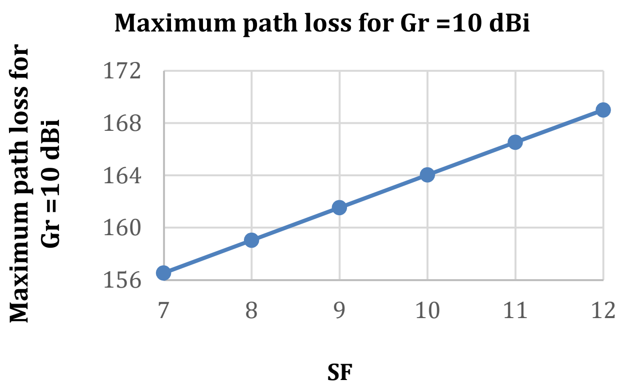

Figure 2 The maximum path loss for the link based on the receiver sensitivity of LoRa for the given spreading factor

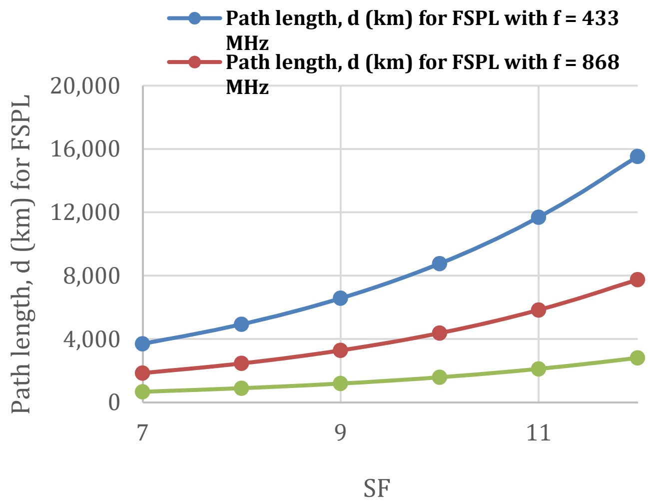

Figure 3 The maximum path length versus spreading factor and frequency for free space path loss model

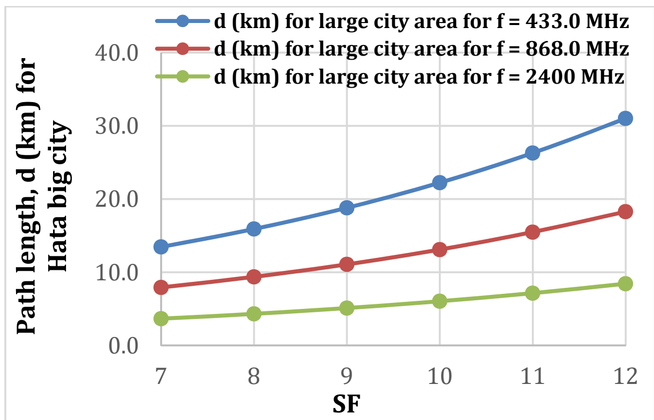

Figure 4 The maximum path length versus spreading factor and frequency for Hata path loss model applied in large city

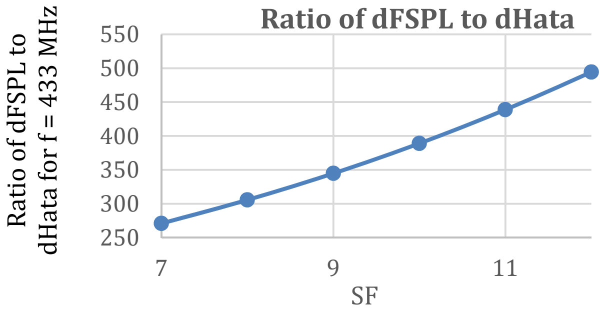

Figure 5 Comparison of the maximum path length versus spreading factor for free space path loss and Hata path loss model applied in large city at the frequency of 433 MHz

IV. Conclusion

Comparison of the transmission range of LoRa transceiver used in satellite application and in terrestrial application is presented. The study employed link budget equations to determine the transmission range of the LoRa transceiver in some selected industrial, scientific and medical (ISM) frequency bands. The free space path loss was used in the case of satellite link while Hata propagation loss model was used for the terrestrial communication link. In all, the results show that the transmission range for the satellite link with free space path model is over 250 times greater than the terrestrial transmission range. Essentially, the impact of the numerous obstacles in the terrestrial wireless link greatly impact on the attainable transmission range.

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