Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 9 Issue 2, February - 2022

Comparative Analysis Of Communication Range Of Lora Sensor Network In The Urban, Suburban And Rural Environments

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***Abstract*— Comparative analysis of communication range of LORA sensor network in the urban, suburban and rural environments is presented. The study used the Hata path loss model to determine the communication range of Semtech SX1272 LoRa transceiver in the rural area, the suburban area, the urban small city area and urban large city area. The study also considered the coverage range for three different operating bandwidths (125 KHz. 250 kHz and 500 kHZ) of the transceiver and for five different spreading factors (SF = 7,8,9,10,11 and 12). The results show that the LoRa sensor network configuration with spreading factor, SF =12 has the best receiver sensitivity value of -137 dBm, the highest path loss value of 140.0 dB and the highest communication range of 17.559 km for the rural/open area, 5.090 km for the suburban area , 3.680 for the urban small city and 3.666 for the urban large city. Also, the results show that among the three bandwidths (125 KHz. 250 kHz and 500 kHZ), the 125 kHz bandwidth has the highest path loss and the highest transmission range. On the other hand, the 500 kHz bandwidth had the lowest path loss and the lowest communication range when compared with the corresponding results in the other bandwidths. Essentially, the results show that it will take more LoRa transceiver resources to cover wider area in the urban large city than in any of the other environments considered. Also, the 125 kHz can be used when wider area need to be covered with the LoRa transceiver. Also, the spreading factor of 12 has the largest coverage radius in all the cases (bandwidths) considered.**

***Keywords*— Transmission Range, Bandwidth, LORA SENSOR NETWORK , Transceiver, Path Loss, Spreading Factor**

1. Introduction

Wireless communication is today the most adopted communication technology across the globe [1,2,3,4,5,6,7,8,9]. The ease of deployment and other salient features are part of the reasons for such wide spread adoption of wireless communication systems. Moreover, wireless networks provide requisite communication framework that enables internet of things and smart system applications, such as smart city, smart home, smart medicine, and smart agriculture [10,11,12,13]. However, wireless commination networks generally have some setbacks which affects its operation and coverage. In view of the setbacks, accurate estimation of the communication range of wireless communication networks are important in their design and deployment [14,15,16,17,18].

Notably, among the several factors that do affect the communication range of wireless signals are environmental factors like obstruction in the signal path; climatic factors like atmospheric temperature, pressure and relative humidity; communication device factors like antenna gain, cable loss, alignment loss; as well as other factors that may fall into different categories [19,20,21,22,23,24,25,26,27,28]. Generally, these factors cause signal attenuation which can be quantified in terms of path loss, diffraction loss, fading and other signal degrading parameters [29,30,31,32,33]. The degradation in signal strength decreases the attainable communication range of the wireless network. In practice, the propagation loss increases with increase in the obstruction in the path of the signal [34,35,36,37,38]. As such, the propagation loss encountered by a wireless signal in the rural area is quite different from the loss the signal will encounter in the suburban and urban areas. Furthermore, the variation in the propagation loss means that different communication ranges will be achieved when the same wireless signal is deployed in the rural, the suburban and the urban environments. Accordingly, in this paper, the variation in the communication range of Long Range (LoRa) sensor network [39,40,41,42,43] in the different environments is studied.

Specifically, the study used an empirical path loss model to estimate the propagation loss in each of the environments considered and then determine the attainable communication range of a LoRa sensor network in each of the environments for different configurations of the LoRa transceiver. Several numerical examples are used to discuss the implications of the different LoRa transceiver configurations on the communication range in each of the different environments considered in the study.

2. Method

2.1 Modelling of LoRa sensor network Propagation Loss

The LoRa sensor network receiver sensitivity (S_{sen}), fade margin, M_{fm}, transmission power (P_t), received power (P_r) and path loss (L_{PL}), along with the antenna gain of the transmitter (G_t) and that of the receiver (G_r) are related as follows;

$$P_r = S_{sen} + M_{fm} = P_t + G_t + G_r - L_{PL} \quad (1)$$

Therefore;

$$L_{PL} = P_t + G_t + G_r - M_{fm} - S_{sen} \quad (2)$$

Also, LoRa sensor network receiver sensitivity (S_{sen}) is related to the bandwidth (BW), the noise Figure (NF) and signal to noise ratio (SNR) as follows;

$$S_{LoRa} = -174 + 10\log_{10}(BW) + NF + SNR \quad (3)$$

Again, the path loss (L_{PL}) is expressed as;

$$L_{PL} = P_t + G_t + G_r - M_{fm} + 174 - 10\log_{10}(BW) - NF - SNR \quad (4)$$

2.1 LoRa sensor network communication range based on Hata Propagation Model

Hata path loss model is computed using the following expressions [44,45,46,47,48,49];

$$LP_{HATA} = A + B * \log_{10}(d) - K \quad (5)$$

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (6)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (7)$$

$$K = \begin{cases} 0 \; for\ Urban\ Area \\ 5.4 + 2 * \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 \; for\ Suburban\ \text{Area} \\ 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) \; for\ Open\ Area/\text{Rural} \end{cases} \quad (8)$$

Where $a(h_m)$ is the antenna height correction factor which is give as;

$$a(h_m) = \begin{cases} [1.1 * \log_{10} f - 0.7] * h_m - [1.56 * \log_{10} f - 0.8] \; for \text{ small city, medium city, open / rural area} \\ 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \; for\ large\ city \text{ f} \leq 200\text{MHz} \\ 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \; for\ large\ city \text{ f} \geq 400\text{MHz} \end{cases} \quad (9)$$

- ✓ f is frequency in MHz ; d is the link distance in km
- ✓ 150 MHz≤ f≤ 1000MHz; 30m ≤h_b ≤ 200m ;1m≤ h_m≤ 10 m and 1 km ≤ d ≤ 20km

Therefore, when Hata model is used, the path length, denoted as d_{eH} is defined as;

$$\text{LP}_{\text{HATA}} = \text{L}_{\text{PL}} = = \text{A} + \text{B} * \log_{10}(\text{d}) - \text{K} = \text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - M_{fm} - S_{sen} \quad (10)$$

$$\text{d}_{\text{eH}} = 10^{\left(\frac{(\text{P}_\text{T} + \text{G}_\text{T} + \text{G}_\text{R} - M_{fm} - \text{P}_\text{S}) - \text{A} + \text{k}}{\text{B}}\right)} \quad (11)$$

3. Results and discussion

The computation of the communication range for LoRa sensor network that use Semtech SX1272 transceiver that is operating in the 868 MHz Band with base station antenna height of 40 m , sensor antenna height of 1 m and zero fade margin. The computation was conducted for the 125 kWHz bandwidth and for spreading factors (SFs) ranging from 7 to 12. The dataset on the receiver sensitivity used is given in Table 1 and Figure 1.

Table 1 The dataset on the receiver sensitivity of Semtech SX1272 LoRa transceiver for spreading factors (SFs) ranging from 7 to 12. [50]

SF, Spreading Factor	Receiver Sensitivity (dBm) for BW= 125 kHz	Receiver Sensitivity (dBm) for BW= 250 kHz	Receiver Sensitivity (dBm) for BW= 500 kHz
7	-124.000	-122.000	-116.000
8	-127.000	-125.000	-119.000
9	-130.000	-128.000	-122.000
10	-133.000	-130.000	-125.000
11	-135.000	-132.000	-128.000
12	-137.000	-135.000	-129.000

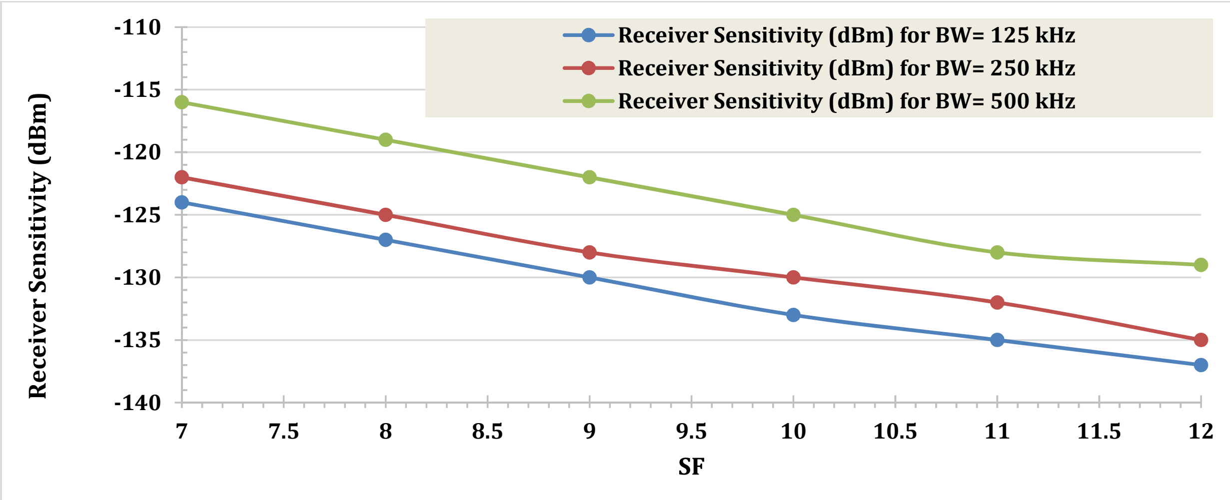

Figure 1 The graph plot of receiver sensitivity versus spreading factor (SF) for Semtech SX1272 LoRa transceiver

The results of the communication range for the urban (city), suburban and Rural/Open environments are shown in Table 2 for different spreading factor (SF) of the LoRa sensor network with zero (0) fade margin. The graph of communication range (d in km) for the urban (city), suburban and rural/open environments versus spreading factor (SF) is given in Figure 2. Also, the graph of Path Loss, LPL (dB) versus spreading factor (SF) is given in Figure 3. The results show that the LoRa sensor network configuration with spreading factor, SF =12 has the best receiver sensitivity value of -137 dBm, the highest path loss value of 140.0 dB and the highest communication range of 17.559 km for the rural/open area, 5.090 km for the suburban area , 3.680 for the urban small city and 3.666 for the urban large city. Essentially, the communication range is highest in the rural area. On the other hand, the LoRa sensor network configuration with spreading factor, SF =7 has the least receiver sensitivity value of -124. dBm and the lowest path loss value of 127 dB. The communication range of the case where SF =7 is such that the communication range of 7.356 km is obtained for the rural/open area, 2.132 km for the suburban area, 1.103 for the urban small city and 1.099 for the urban large city.

Table 2 The results of the communication range for the urban (city), suburban and Rural/Open environments

SF, Spreading Factor	SNR (dB) Required for BW of 125 KHz	Receiver Sensitivity (dBm)	Path Loss, LPL (dB)	d (km) for Hata Rural/open Area	d (km) for Suburban Area	d (km) for Small City Area	d (km) for Large City Area
7	-7.5	-124	127	7.356	2.132	1.103	1.099
8	-10	-127	130.0	8.992	2.607	1.442	1.437
9	-12.5	-130	133.0	10.991	3.186	1.884	1.877
10	-15	-133	136.0	13.435	3.895	2.463	2.454
11	-17.5	-135	138.0	15.359	4.452	3.010	2.999
12	-20	-137	140.0	17.559	5.090	3.680	3.666

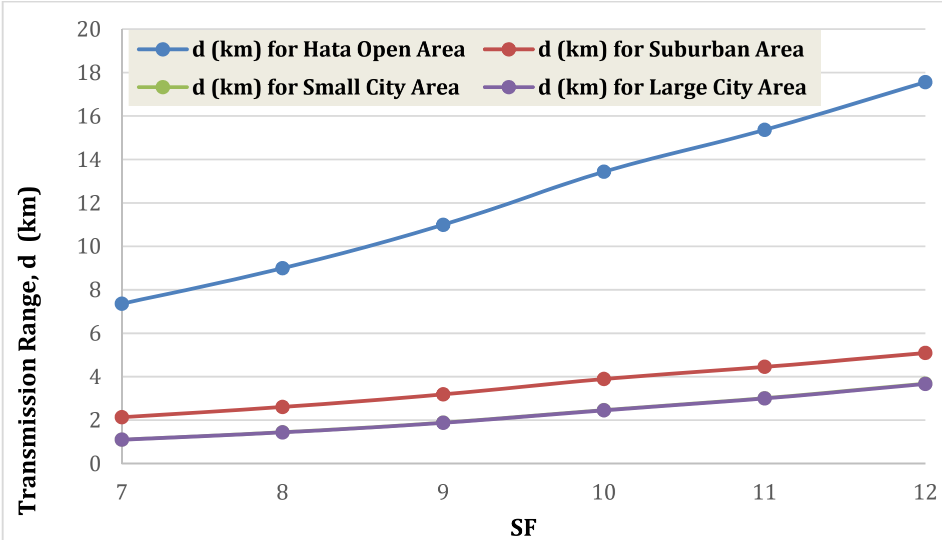

Figure 2 The graph of communication range (d in km) versus spreading factor for the 125 kHz bandwidth

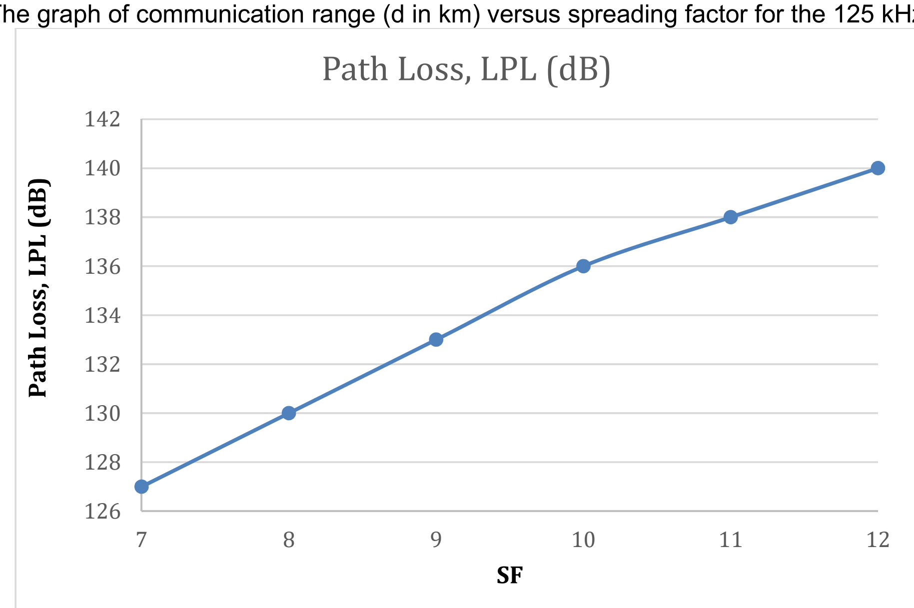

Figure 3 The graph of the path loss (in dB) versus spreading factor , SF f or the 125 kHz bandwidth

The graph of the path loss (in dB) versus spreading factor, SF for the125 kHz, 250 kHz and 500 kHz bandwidth is shown in Figure 4. Also, the graph of communication range (d in km) in the rural area versus spreading factor for the125 kHz, 250 kHz and 500 kHz bandwidth is shown in Figure 5, the graph of communication range (d in km) in the suburban area is shown in Figure 6, the graph of communication range (d in km) in the urban small city is shown in Figure 7, while the graph of communication range (d in km) in the urban large city is shown in Figure 8.

In all, the results show that the 125 kHz bandwidth has the highest path loss and the highest communication range when compared to the 25o kHz and 500 kHz bandwidths. On the other hand, the 500 kHz bandwidth had the lowest path loss and the lowest communication range when compared with the corresponding results in the other bandwidths. Essentially, the results show that it will take more LoRa transceiver power to cover wider area in the urban large city than in any of the other areas considered. Also, the 125 kHz can be used when wider area need to be covered with the LoRa transceiver. Also, the spreading factor of 12 has the largest coverage radius in all the cases (bandwidths) considered.

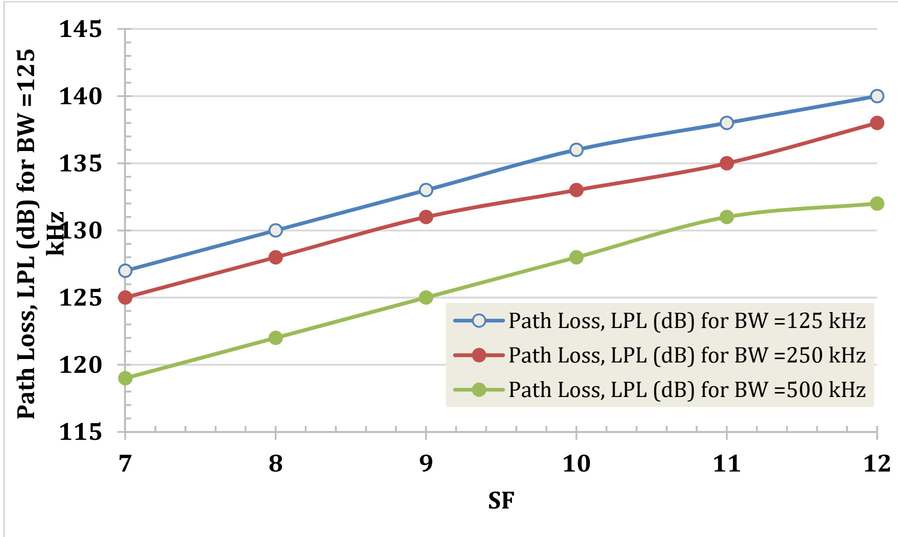

Figure 4 The graph of the path loss (in dB) versus spreading factor, SF for the125 kHz, 250 kHz and 500 kHz bandwidth

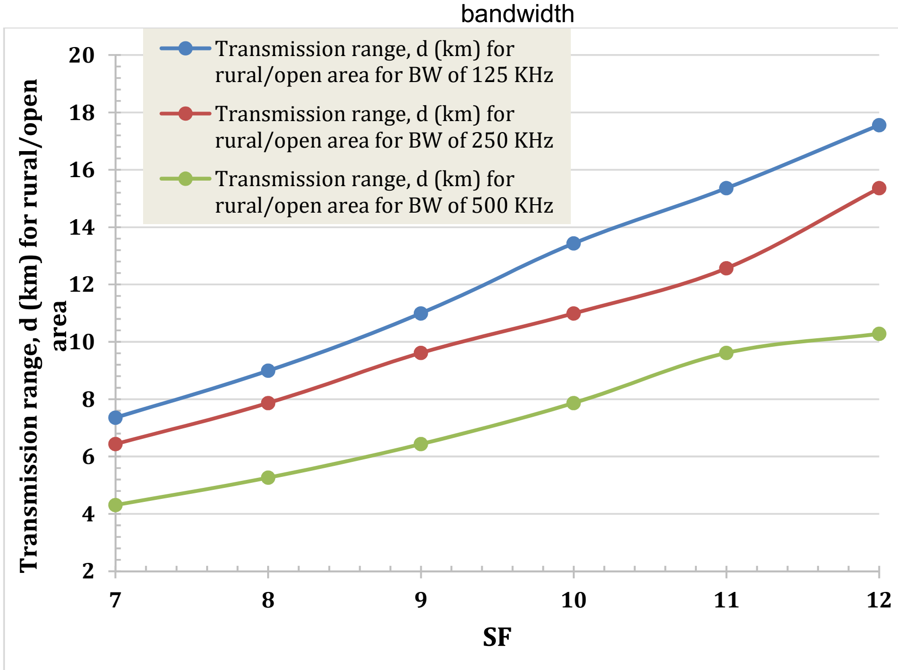

Figure 5 The graph of communication range (d in km) in the rural area versus spreading factor for the125 kHz, 250 kHz and 500 kHz bandwidth

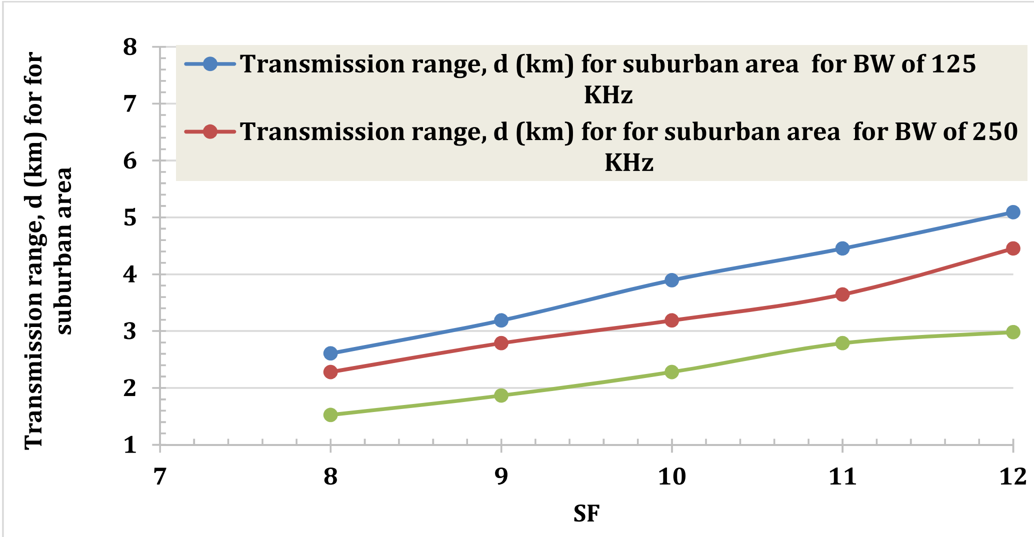

Figure 6 The graph of communication range (d in km) in the suburban area versus spreading factor for the125 kHz, 250 kHz and 500 kHz bandwidth

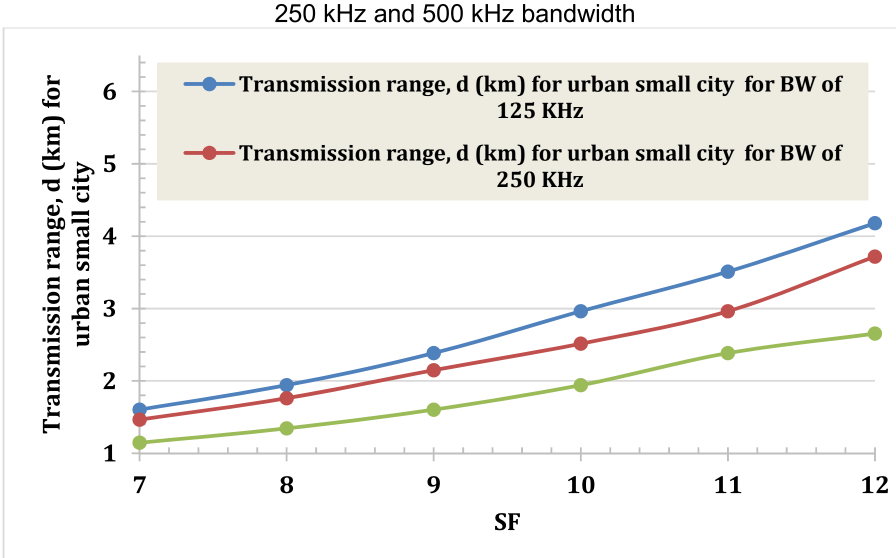

Figure 7 The graph of communication range (d in km) in the urban small city versus spreading factor for the125 kHz, 250 kHz and 500 kHz bandwidth

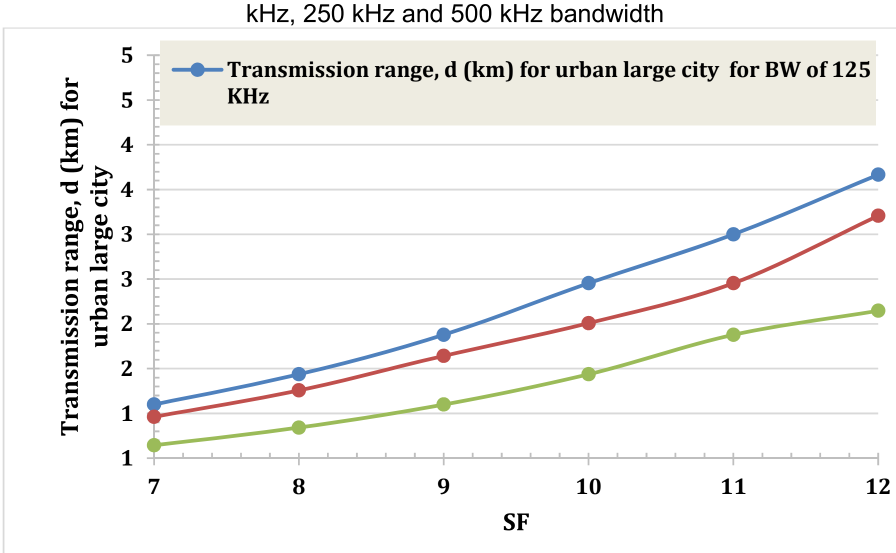

Figure 8 The graph of communication range (d in km) in the urban large city versus spreading factor for the125 kHz, 250 kHz and 500 kHz bandwidth

4. Conclusion

Evaluation of the communication range of LoRa sensor network in different environments is presented. The study used the Hata path loss model to determine the communication range of Semtech SX1272 LoRa transceiver in the rural area, the suburban area, the urban small city area and urban large city area. The study also considered the coverage range for three different operating bandwidths of the transceiver and for five different spreading factors. The results show that the communication range is highest in the rural area and least in the urban large city environment.

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