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# Characterization of Rain Attenuation Statistics for 5G Communication System in the Equatorial Region

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## ABSTRACT

The increasing demand for high data rates in the current communication system leads to the evolution of 5G technology. Therefore, it is of great interest to study the impact of path length and frequency for the 5G network. This paper presents the rain attenuation statistics for the 5G communication system in heavy rain regions using rainfall data collected over three years in Kuala Lumpur. From the analysis, the rain attenuation for a 0.2 km 5G terrestrial path link is less than 5 dB. Furthermore, it is found that monthly statistics are more significant and the analysis indicates that inter-monsoon season records the highest attenuation followed by northeast and southwest seasons. In addition, the predicted statistical result using the Synthetic Storm Technique and ITU-R model provides crucial information for future 5G architectural planning, as well as the network operators who plan to operate their services in this particular equatorial region.

**Key words :** 5G, ITU-R model, Rain attenuation, SST model, Terrestrial link.

## 1. INTRODUCTION

The emergence of advanced and new mobile handsets technologies especially the need for internet access on almost entire applications causing network congestion at a lower frequency spectrum. The continuous and increasing demands of consumers have brought to the launching of 5G technology. Development of 5G technology targets to increase bandwidth, improve spectral efficiency as well as the ability to support high data rates and more devices effectively [1], [2]. 5G technology especially the 5G Long Term Evolution Advanced (LTE-A) is certainly an enhancement and good technology in Internet of Things (IoT) applications that has been expanded in many areas like transportation, smart city healthcare, industrial and electricity [3], [4]. Nevertheless, the 5G radio links that operating at a frequency higher than 10 GHz might be affected by the atmospheric phenomenon, particularly rain. In tropical regions, the rain intensity is high, and it often happens because rainfall is a common phenomenon in this region [5]. For the terrestrial line-of-sight link, a transmission path is set up between the transmitter and receiver, as shown in Figure 1. Raindrops are absorbed and scattered by the electromagnetic waves and lead to signal attenuation. Besides, the impact of frequency and path length are also significant for the 5G network [6], and this will further discuss in the later section. The real measurement work presented in [7] shows that 28 and 38 GHz are the frequencies that can be used for the 5G network.

In this paper, the study aims to characterize the rain attenuation statistics for the 5G communication system in equatorial Malaysia. The rain attenuation was predicted using ITU-R P.530-17 [8] model and Synthetic Storm Technique (SST) [9].

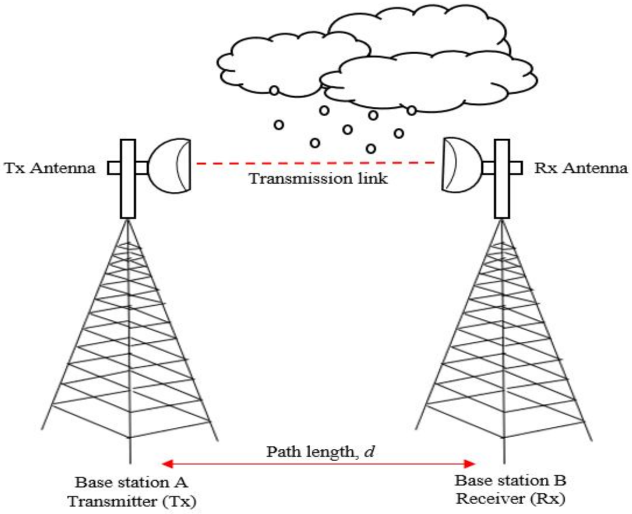

**Figure 1:** Scenario of terrestrial link during rainfall

The structure of the paper is as follows. The prediction models are briefly discussed in Section 2 and the data processing of the rainfall rates is presented in Section 3. Section 4 summarised the statistical results and discussion of the predicted rain attenuation. Finally, conclusions are drawn in Section 5.

## 2. RAIN ATTENUATION PREDICTION MODEL

ITU-R model is a well-known and widely used prediction model of all the existing rain attenuation prediction models in the communication link. ITU-R P.530-17 [8] provides the prediction methods for the terrestrial line-of-sight system. This prediction method is highly dependent on the specific attenuation, $\gamma$ and path reduction factor, $r$ as demonstrated in (1) and (2). Specific attenuation is calculated based on the power-law relationship between rain rate, $R$ and specific attenuation, $\gamma$ which has been included in [10].

$$\gamma = kR^{\alpha} \tag{1}$$

$$r = 1/(0.477d^{0.633}\, R_{0.01}^{0.073\propto}\, f^{0.123} - 10.579(1 - \exp(-0.024d))) \tag{2}$$

where the constant $k$ and $\alpha$ are the function of frequency, $f$ from 1 to 1000 GHz with respect to horizontal and vertical polarization, $d$ is the path length and $R_{0.01}$ is the rainfall rate at 0.01% of the time. According to [8], the recommended $r$ value is 2.5 for the denominator in (2) which is less than 0.4.

The path length $d_{eff}$ as derived in (3) is one of the essential factors and needed to be considered in the interest of computing path attenuation. It is the hypothetical length along the path in which the attenuation is resulted from a point rainfall rate that occurs at any time percentage and can be determined by multiplying the actual path length, $d$ by the reduction factor, $r$ at 0.01% of time exceedance calculated from (2). The path attenuation, $A$ exceeded at 0.01% of the time can be estimated from (4).

$$d_{eff} = dr_{0.01} \tag{3}$$

$$A_{0.01} = \gamma d_{eff} \tag{4}$$

Another option to predict the rain attenuation is by applying the Synthetic Storm Technique (SST) developed by Matricciani [9]. It is a physical-mathematical model that able to convert time series of rain rate into time series of rain attenuation. This model can be used to predict rain attenuation in terrestrial line-of-sight links [11] as well as in satellite links [12]. Horizontal wind speed at 700 mbar pressure level is initially estimated to convert rain rate time series into rain rate space series. By assuming that a point positioned along the x-axis with rainfall rate, $R$ measured at the same location, the attenuation, $A$ along the path is calculated using expression (5).

$$A(x_o) = k \int_{x_o - L/2}^{x_o + L/2} R^{\propto}(x)dx \tag{5}$$

The $k$ and $\alpha$ of the rain layer should be used in (5) for terrestrial link applications. The attenuation with time is restricted through the changing of path distance along the x-axis at a rate equal to the advection velocity, $v$ of rain cell as expressed in (6). This can also be computationally represented as the convolution between rectangular unit amplitude and width centralized at origin described in (7) and (8).

$$x_o = vt \tag{6}$$

$$A(x_o) = k \int_{-\infty}^{\infty} R^{\propto}(x_o + x)rect\left(\frac{x}{L}\right)dx \tag{7}$$

$$A(x_o) = k \int_{-\infty}^{\infty} R^{\propto}(x)rect\left(\frac{x_o - x}{L}\right)dx \tag{8}$$

## 3. DATA PROCESSING

In this work, the rain attenuation is predicted using 3-years of 1-minute rain data collected from the year 1992 to 1994 in Kuala Lumpur, Malaysia. Both ITU-R P.530-17 and SST models are used to predict the rain attenuation. The local horizontal wind speed at the pressure level of 700 mbar is 6.2 m/s [12]. The rainfall rate at 0.01% of the time used for the ITU-R model is 141 mm/hr and vertically polarization is used. The $k$ and $\alpha$ coefficient values used for both prediction models at three different frequencies in this study are tabulated in Table 1. The results are compared to evaluate the impact of path length and frequency as well as the monsoon effect on the 5G network. Likewise, the predicted result has also compared with the rain attenuation predicted in the temperate region [13]. The effective path length is used as the actual path length particularly for path length that more than 1.8 km.

**Table 1:** Coefficients $k$ and $\alpha$ values used for SST and ITU-R models at three different frequencies

| Frequency (GHz) | $k$ (SST) | $\alpha$ (SST) | $k$ (ITU-R) | $\alpha$ (ITU-R) |
|---|---|---|---|---|
| 20 | 0.089639 | 1.0154 | 0.0961 | 0.9847 |
| 26 | 0.148438 | 0.9967 | 0.1669 | 0.9421 |
| 30 | 0.200858 | 0.9771 | 0.2291 | 0.9129 |

## 4. RESULT AND DISCUSSION

Figure 2 presents the impact of path length at frequency 26 GHz on yearly statistics. It is clearly shown that the attenuation increases with the increasing path length. At 0.01% of the time, the attenuation at 0.2 km path length for 5G network is less than 5 dB whereas the attenuation reaching 38 dB when path length increased to 2 km. Therefore, due to the high attenuation on longer path length, 0.2 km path length is proposed for the 5G network. Besides, Figure 3a and 3b show the monthly statistics of path length for 0.2 km and 3 km, respectively at 28 GHz in equatorial Malaysia. The result reveals lower rain attenuation occurs in August whereas November recorded the highest rain attenuation. The impact of monsoon season on rain attenuation is depicted in Figure 4. It is reported that inter-monsoon season occurring during April, May, October and November [14] has the highest rain attenuation while the southwest season from June to September has lower rain attenuation. The rain attenuation at a different percentage of time exceedance for path length 0.2 km, 1 km, and 2 km as well as different monsoon seasons are compared and summarized in Table 2.

**Table 2:** Predicted rain attenuation at 28 GHz for three seasons in Malaysia

| Percentage of time exceedance (%) | Rain attenuation (dB) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Northeast | | | Southwest | | | Intermonsoon | | |
| | 0.2 km | 1 km | 2 km | 0.2 km | 1 km | 2 km | 0.2 km | 1 km | 2 km |
| 1 | 0.179 | 0.922 | 1.748 | 0.137 | 0.711 | 1.382 | 0.274 | 1.455 | 2.766 |
| 0.1 | 2.263 | 11.628 | 20.547 | 1.832 | 9.334 | 16.925 | 2.589 | 13.113 | 23.112 |
| 0.01 | 4.735 | 23.842 | 41.711 | 3.532 | 17.525 | 31.551 | 4.543 | 22.631 | 39.487 |

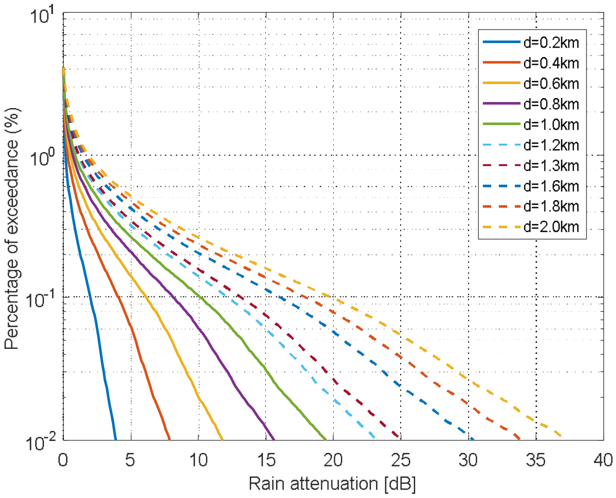

**Figure 2:** Impact of path length at 26 GHz

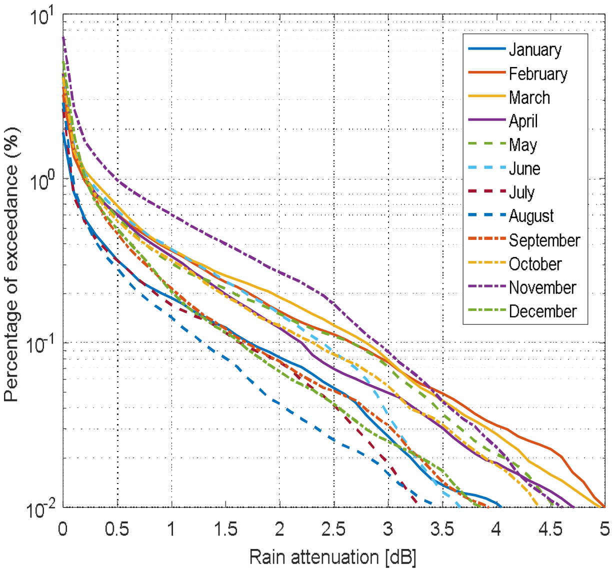

**Figure 3a:** Monthly statistics at 28 GHz at 0.2 km

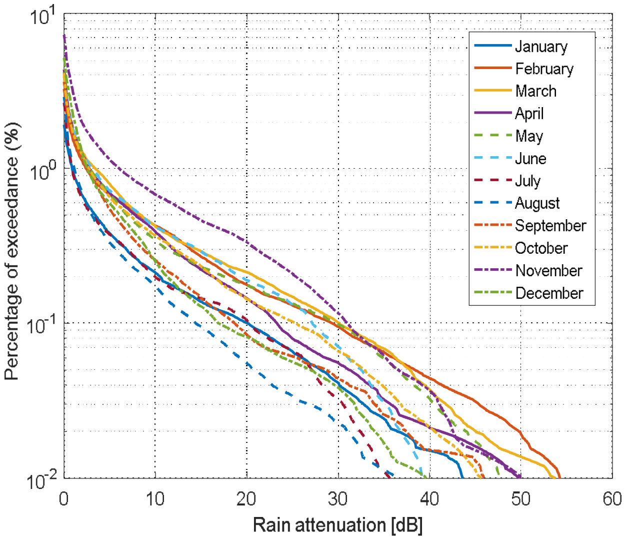

**Figure 3b:** Monthly statistics at 28 GHz at 3 km

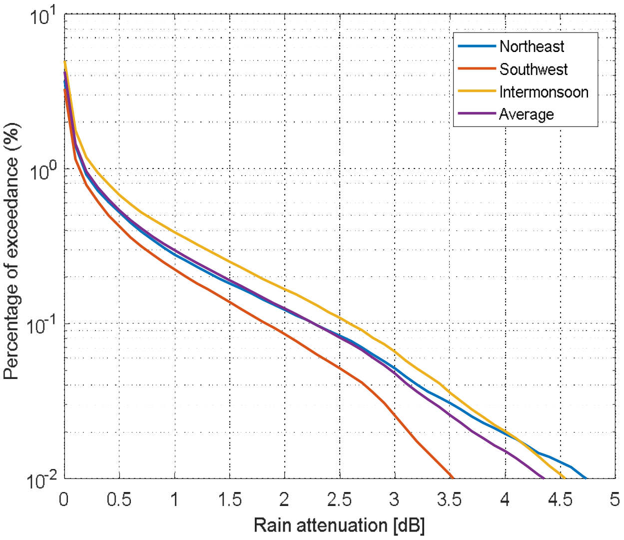

**Figure 4:** Impact of monsoon season at 0.2 km

**Table 3:** Rain attenuation at different frequencies for 1.3 km and 5 km of path length

| Path length (km) | Percentage of time exceedance (%) | Prediction model | Rain attenuation (dB) | | |
|---|---|---|---|---|---|
| | | | 20GHz | 26GHz | 30GHz |
| 1.3 | 1 | SST | 0.725 | 1.158 | 1.509 |
| | | ITU-R | 2.084 | 2.807 | 3.268 |
| | 0.1 | SST | 8.605 | 13.153 | 16.372 |
| | | ITU-R | 7.379 | 10.118 | 11.896 |
| | 0.01 | SST | 16.594 | 25.074 | 30.818 |
| | | ITU-R | 19.477 | 26.756 | 31.487 |
| 5.0 | 1 | SST | 1.995 | 3.016 | 3.833 |
| | | ITU-R | 4.386 | 5.870 | 6.816 |
| | 0.1 | SST | 20.046 | 29.435 | 36.012 |
| | | ITU-R | 15.529 | 21.156 | 24.807 |
| | 0.01 | SST | 37.522 | 54.479 | 65.988 |
| | | ITU-R | 40.990 | 55.943 | 65.660 |

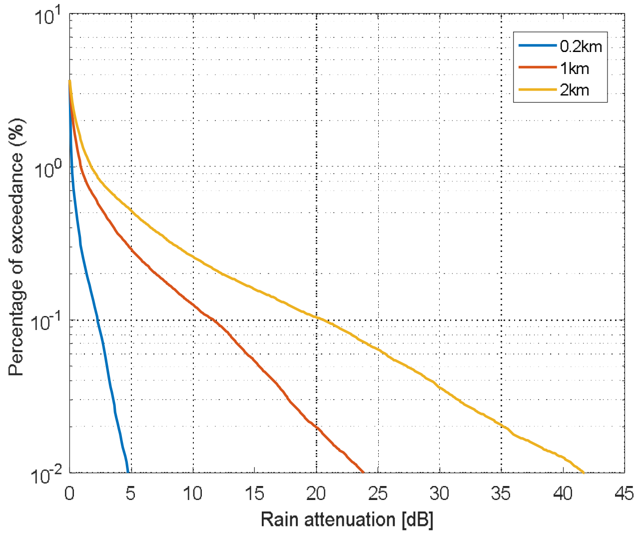

**Figure 5a:** Impact of path length during the northeast season at 28 GHz

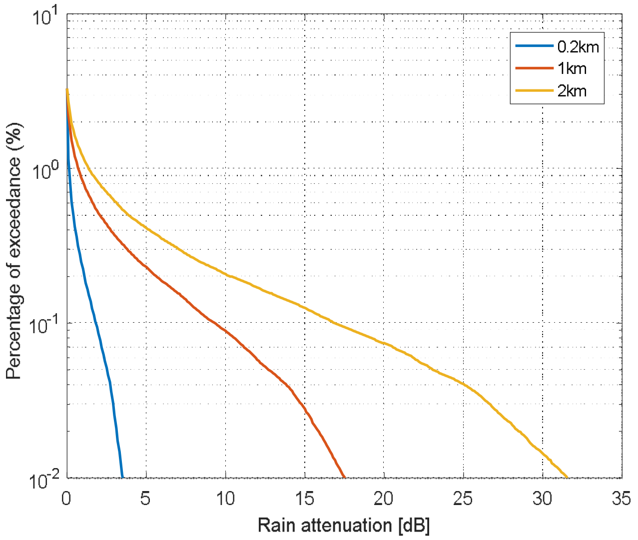

**Figure 5b:** Impact of path length during the southwest season at 28 GHz

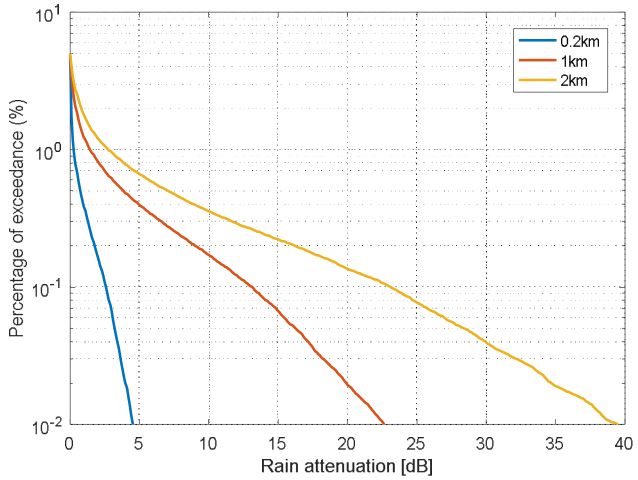

**Figure 5c:** Impact of path length during the intermonsoon season at 28 GHz

The impacts of path length at 28 GHz based on northeast, southwest and inter-monsoon season are presented in Figure 5a, 5b and 5c respectively. It can be seen that the predicted rain attenuation during the northeast season for path length 0.2 km is 4.735 dB at 0.01% time of exceedance. When the path length increase to 1 km, the rain attenuation increase dramatically and reaching 23 dB. It is then increased to 41 dB when the path length has increased to 2 km. The rain attenuation at path length 0.2 km during the southwest season is 3.532 dB which is the lowest rain attenuation recorded among the three seasons in Malaysia at 0.01% of time exceeded. Rain attenuation during the southwest season at a path length of 1 km and 2 km are 17.525 dB and 31.551 dB respectively. During inter-monsoon season, the rain attenuation at 0.01% of the time is 4.543 dB at 0.2 km and then rising to 22.631 dB at 1 km and 39.487 dB at 2 km. This proves that path length plays an important role in determining rain attenuation. Besides that, the predicted rain attenuation using SST and ITU-R models for different frequencies at 1.3 km path length has been evaluated and depicts in Figure 6. At 1% and 0.01%, SST has lower attenuation as compared to the ITU-R model. However, SST has higher attenuation against the ITU-R model at 0.1% time of exceedance. Using SST model, the rain attenuation of 0.725, 8.605 and 16.594 dB in parallel 1.509, 16.372 and 30.818 dB were obtained in 1%, 0.1% and 0.01% of time for 20 and 30 GHz respectively. Meanwhile, by using the ITU-R model, rain attenuation of 2.084, 7.379 and 19.477 dB were achieved for 20 GHz and 3.268, 11.896 and 31.487 dB for 30 GHz at 1%, 0.1%, and 0.01%. The predicted rain attenuation for different frequencies and path lengths is compared and tabulated in Table 3.

On top of that, the predicted rain attenuation in tropical regions in Kuala Lumpur, Malaysia was also compared with the predicted rain attenuation at the temperate region in Milan, Italy [13] and is demonstrated in Figure 7. The rain attenuation is predicted for 5 km path length at 30 GHz of frequency. Despite that, the rain attenuation in tropical regions is predicted using SST and ITU-R models while the prediction model used in the temperate region is MultiEXCELL [13]. The $k$ and $\alpha$ coefficient values used in these models has tabulated in Table 1. At 1% time of occurrence, the rain attenuation predicted using the SST model in the tropical region is lower as compared to the rain attenuation predicted using the ITU-R model and in the temperate region. However, the rain attenuation predicted using the SST model is increased and higher than the rain attenuation in the temperate region as well as the ITU-R model predicted in the tropical region at both 0.1% and 0.01% time of occurrence. At 0.01%, the rain attenuation in Milan is 47 dB. In Kuala Lumpur, the rain attenuation is 65.66 dB when predicted using the ITU-R model and 66 dB for the SST model. It is obviously shown that the predicted rain attenuation in tropical regions is higher than in the temperate region. This occurrence may be due to the high rain intensities throughout the year in tropical regions. Beyond that, the rain attenuation predicted using SST is slightly higher in accordance with ITU-R model.

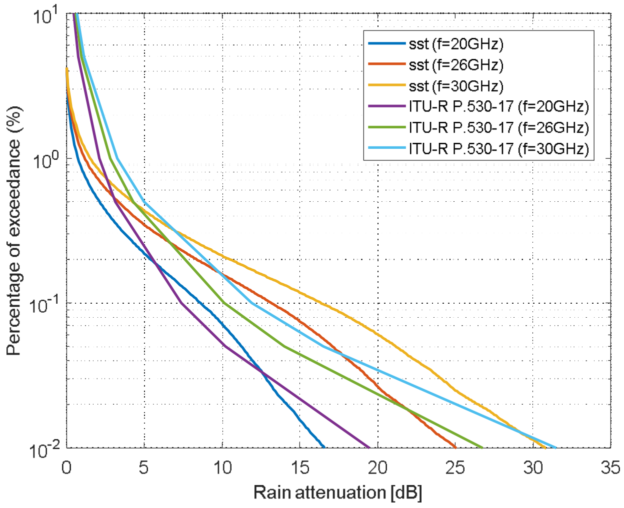

**Figure 6:** Predicted rain attenuation at different frequencies for 1.3 km path length

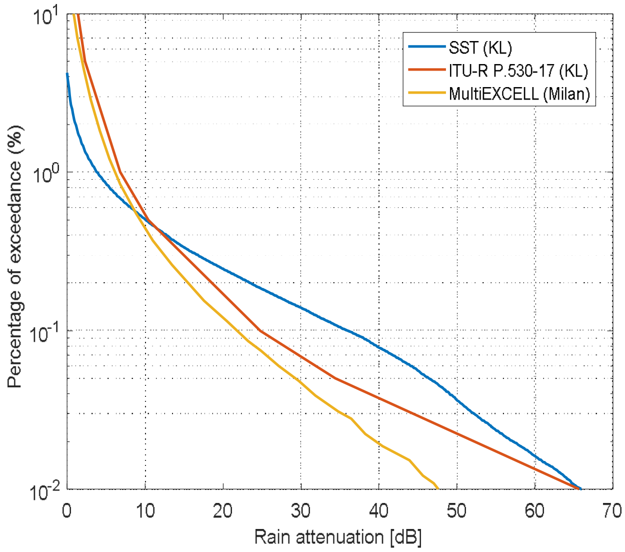

**Figure 7:** Comparison of predicted rain attenuation at the tropical and temperate region

## 5. CONCLUSION

Based on the presented results for the studies on the 5G network link, the predicted statistics of rain attenuation for 5G candidate frequencies are subsequently presented for short path length links. The existing rain attenuation models were used to compare the predicted results in terms of different path lengths and frequency as well as the monsoon effect. It can be clearly noticed that the monthly statistics are significantly higher than the yearly statistics. It can also be concluded that if the distance between the base station is as short as only 200 m, the rain attenuation is lower and link performance is better. Additionally, the predicted rain attenuation using the SST model follows closely with the rain attenuation predicted by using the ITU-R model. Both prediction models can be used for the prediction of 5G signal attenuation. The outcomes are of great importance for the implementation of 5G cellular communications in heavy rain regions.

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## REFERENCES

1. Andrews, J. G., Buzzi, S., Choi, W., Hanly, S. V., Lozano, A., Soong, A. C. K., and Zhang, J. C. **What will 5G be?**, *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065–1082, 2014. https://doi.org/10.1109/JSAC.2014.2328098
2. Vora, M. L. J. **Evolution of mobile generation technology : 1G To 5G and review of upcoming wireless technology 5G**, *International Journal of*

*Modern Trends in Engineering and Research*, vol. 2, no. 10, pp. 281–290, 2015.

3. Khdhir, R., and Belghith, A. **5G LTE-A cognitive multiclass scheduling scheme for Internet of Things**, *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 5, pp. 2485–2491, 2019. https://doi.org/10.30534/ijatcse/2019/94852019
4. Setyo, J., Gunawan, A., Rizki, M., and Wang, G. **Challenge of 5G network technology for telemedicine and telesurgery**, *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 6, pp. 3680–3683, 2019. https://doi.org/10.30534/ijatcse/2019/154862019
5. Lam, H. Y., Din, J., and Jong, S. L. **Statistical and physical descriptions of raindrop size distributions in equatorial Malaysia from disdrometer observations**, *Advances in Meteorology*, pp. 1–14, 2015.
6. Nandi, D., and Maitra, A. **Study of rain attenuation effects for 5G Mm-wave cellular communication in tropical location**, *IET Microwaves, Antennas and Propagation*, vol. 12, no. 9, pp. 1504–1507, 2018.
7. Rappaport, T. S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., Wong, G. N., Schulz, J. K., Samimi, M., and Gutierrez, F. **Millimeter wave mobile communications for 5G cellular: it will work!**, *IEEE Access*, vol. 1, pp. 335–349, 2013.
8. ITU-R P.530-17. **Propagation data and prediction methods required for the design of terrestrial line-of-sight systems**, *Recommendation ITU-R*, pp. 1–24, 2017.
9. Matricciani, E. **Physical-mathematical model of the dynamics of rain attenuation based on rain rate time series and a two-layer vertical structure of precipitation**, *Radio Science*, vol. 31, no. 2, pp. 281–295, 1996.
10. ITU-R P.838-3. **Specific attenuation model for rain for use in prediction methods**, *Recommendation ITU-R*, pp. 1–8, 2005.
11. Mandeep, J. S. **Rain attenuation statistics over a terrestrial link at 32.6 GHz at Malaysia**, *IET Microwaves, Antennas & Propagation*, vol. 3, no. 7, pp. 1086–1093, 2009.
12. Jong, S. L., Riva, C., D’Amico, M., Lam, H. Y., Yunus, M. M., and Din, J. **Performance of synthetic storm technique in estimating fade dynamics in equatorial Malaysia**, *International Journal of Satellite Communications and Networking*, vol. 36, no. 5, pp. 416–426, 2018.
13. Ghiani, R., Luini, L., and Fanti, A. **A physically based rain attenuation model for terrestrial links**, *Radio Science*, vol. 52, no. 8, 972–980, 2017. https://doi.org/10.1002/2017RS006320
14. Jong, S. L., Lam, H. Y., Amico, M. D., and Din, J. **Analysis of precipitation characteristics over Southern Peninsular Malaysia for satellite propagation application**, in *2016 URSI Asia-Pacific Radio Science Conference (URSI AP-RASC)*, 2016, pp. 1729–1732.