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The Comparison and Analysis on Fog and Haze Attenuation in Asian Countries

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Abstract

Haze is usual atmospheric phenomenon in several countries especially in Asian countries. Fog can happen in every countries around the world, however, in Asian countries especially in tropical regions formation of fog is hardly visible expect during dawn or around higher latitude. Therefore, haze and fog attenuation in millimeter wave in Asian countries need more focused and further research. The scattering and absorption caused by the particles can be huge issues in implementing millimeter wave in Asian countries. Fog has higher chances in causing attenuation in millimeter wave. Even though haze usually caused scattering in light but there are higher possibility that it can also affect microwave links especially in higher frequency

Keywords; *Haze attenuation, fog attenuation, millimeter wave, 5G*

I. INTRODUCTION

Increasing demands in mobile data have expanded over 50% and expected to expand in the next decade [1]–[3]. Therefore, fifth generation (5G) was introduced by the 3rd Generation Partnership Project (3GPP) that can overcome the global bandwidth shortage [4]–[6]. Thus, it can help the mobile service provider in order to provide a better service to their customers.

In addition, 5G can also support a wide array of spectrum bands. The difference between previous generation and 5G is that the 5G can support licensed, shared and unlicensed spectrum bands unlike before which only support licensed spectrum bands below 3GHz. Moreover, 5G spectrum consists of spectrum below 1GHz for low-bands, mid-bands which range in between 1GHz and 6GHz and high-bands that starting from 24GHz and above [7]. Which also known as millimetre wave (mmWave) as shown in Figure 1.

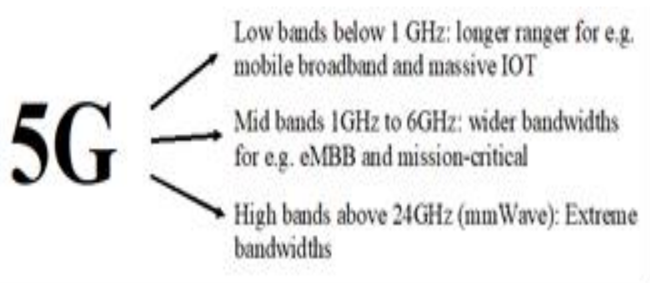

Fig. 1. Suggested 5G spectrums by ITU-R [7]

Fog can be considered as one of the dominant factors in causing attenuation in millimeter wave. Coastal areas had been said to have higher possibility of fog attenuation due to dense moist fog with high liquid water content (LWC) and larger drop size [8]. Four most important parts of fog characterizations are liquid water content (g/m3), visibility, drop size distribution and temperature. Fog attenuation is caused by the absorption and scattering of the wavelength. However, majority of the researchers agreed that rain happened to be one of the biggest obstacles especially for frequency

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above 10GHz[9], [10].

Fog will transform into haze when the relative humidity is low, this is due to the particles dehydrate. In general, fog can be divided into advection fog and radiation fog. Advection fog basically form when the warm air moving to underlying surface cold air; e.g. sea fog. Besides, radiation fog mainly happens in inland due to the cooling of the ground radiation. This paper will be focusing on the attenuation caused by radiation fog.

Haze in Asian countries had becoming serious issue in the past few years. One of the biggest haze crisis happened in Southeast Asian on 2015 where it affected several countries. During this crisis, Malaysia and Singapore received the biggest threat on haze where the Air Pollution Index (API) surpassed 200. However, researches on the effect of haze in microwave links is quite limited due to it rarely happening in certain part of the world [11]. Majorly, haze consists of dust and soot which causing scattering of the millimetre wave.

Hydrometeors and aerosols in fog and haze will cause scattering in millimetre wave. This is matter need to be look into because there are huge possibility both of it can undermines the directional transmission characteristics of millimetre wave in different degrees. This can caused serious deteriorate in millimetre wave due to attenuation, phase-shift and some other transmission effects to millimetre wave, as well as distortion to signal wave form.

In this paper, it will explain on the important roles of LWC and the size of particles in causing scattering and absorption of a wavelength. Besides that, it will also explain and discuss the effect of fog and haze attenuation rate in terms of dB/km in selected Asian countries.

The rest of the paper is organized as follow. Section II explained the method used to obtain the attenuation rate in dB/km. Section III discussed on the specific attenuation caused by fog in Malaysia, South Korea and Qatar with different LWC. Next, Section IV discussed on the attenuation rate caused by haze in Malaysia, South Korea and Qatar with different size of particles. And finally, Section V concluded this paper and suggested future work.

II. METHODOLOGY

A. Fog

Location that is at high altitude and experience low temperature is has high tendency to have fog covering the area. Fog which built up because the temperature is below dew-point temperature has water particles condensed and suspended in the air. Fog in the area can affect the signal strength of propagating radio signal. Since, fog is basically water droplets then it also possessed greater effect in millimeter wave.

As mentioned in ITU-R P.840-7, the loss for frequency greater than 100 GHz may be significant where LWC is around 0.05 g/m3 with 300m visibility. In order to find the value of LWC in surrounding area, the size distribution of the fog droplets need to be determine by using modified gamma drop size distribution (MSDSD). The fog size distribution as shown in formula (1).

$$C_r = N_0 r^m \exp(-\Lambda r^\sigma) \Delta r 0 \leq r \leq \infty \quad (1)$$

(1)

Where r is the fog particle radius, in general, , , are the parameter that characterize the particle size distribution. When σ is equal to 1, , , can be characterized depending on the thickness of the fog. The values for dense fog are 0.027, 3 and 0.3, respectively. However, moderate fog vales are 607.5, 6 and 3.

When the size distribution, is obtained, it can be included in LWC formula. Assuming the concentration of fog is denoted by , LWC formula is as follows:

$$\mathrm{M} = \rho_w \mathrm{N}_d \frac{4}{3} \int_0^\infty \pi r^3 \, \mathrm{C}_r \mathrm{dr} \quad (2)$$

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(2)

Where is density of water in ( ) and M is liquid water content in ( ). After finding the values for LWC, the specific attenuation, , formula (3) is used to calculate the attenuation rate in dB/km as per ITU-R P.840-7.

$$\gamma_C = K_l M \quad (3)$$

(3)

Where is in dB/km, is water specific attenuation coefficient in ((dB/km)/(g/m3)), and is the liquid water density in (g/m3) that had been obtained from equation (2).

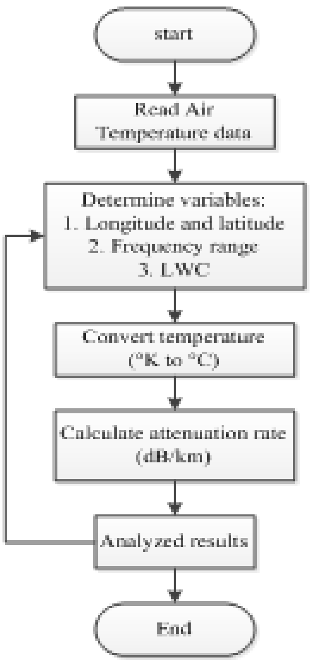

Fig. 2. The flowchart to determine fog attenuation in dB/km

Generally, the values of the LWC can also be determine by the fog visibility (m) whereas 0.05 g/m3 is equal to medium fog where the visibility is around 300 m. Next, for LWC of 0.5 g/m3 can be considered as dense fog with the visibility less than 50 m. However, highest possible value for LWC in fog is 1.0 g/m3. Thus, by assuming that the values LWC are 0.05 g/m3, 0.5 g/m3 and 1.0 g/m3 the attenuation rate in several Asian countries can be determine. Fig. 2.shows the flow of the methodology in determine the fog attenuation in dB/km.

B. Haze

Not only haze could affect the health of human being, but it has negative effect on radio propagation as well. Containing dust, sulfuric acid, nitric acid and other numerous particles haze form when the water component in fog reduces or evaporate. In total, authorities agree that there are 6 types of categories namely soluble particles, sea salt particles and sulfate particles, insoluble particles, dust particles and soot [12].

Since the behavior and characteristic of haze and fog is quite similar, the formula to calculate specific attenuation for haze can be adopted from fog attenuation formula. Haze particle size in general being PM(x) where the x is the size of particle in µm; e.g. PM2.5 which has particle in size of 2.5µm and PM10 which has particle in size of 10µm.

However, there are no model specifically tackling haze attenuation had been suggested by the ITU-R, therefore, formula (12) was designed to calculate the attenuation caused by haze by focusing on the diameter of the particles, particles density and materials density. Firstly, the haze coefficient can be populated by using Double Debye formula. The formula include permittivity component of haze as follows:

$$\varepsilon' = \frac{\varepsilon_0 - \varepsilon_1}{[1 + (f/f_p)^2]} + \frac{\varepsilon_1 - \varepsilon_2}{[1 + (f/f_s)^2]} + \varepsilon_2 \quad (4)$$

$$\varepsilon'' = \frac{f(\varepsilon_0 - \varepsilon_1)}{[1 + (f/f_p)^2]f_p} + \frac{f(\varepsilon_1 - \varepsilon_2)}{[1 + (f/f_s)^2]f_s} \quad (5)$$

By calculating the real and imaginary parts of complex permittivity as shown in equation (4) and (5), the complex permittivity of water, , can be obtained.

Where;

$$\varepsilon_0 = 77.66 + 103.3\,(\theta - 1) \quad (6)$$

$$\varepsilon_1 = 5.48 \quad (7)$$

$$\varepsilon_2 = 3.51 \quad (8)$$

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Mie scattering theory is used to determine the scattering caused by haze particles. It also stated that if the particle has diameter, r, and relative complex dielectric constant, ε, then attenuation coefficient, , and the cross section of the scattering, , can be derived as:

$$\alpha_m = 4.343 \int_{r_{min}}^{r_{max}} Q_s(r) n_m(r)\, \mathrm{n(r)}\, d_r \quad (9)$$

Which;

$$Q_s = \frac{128\pi^5 r^6}{3\lambda^4} \left|\frac{\varepsilon - 1}{\varepsilon + 2}\right|^2 \quad (10)$$

Lets' assume n(r) represent the number of particle consist in a unit volume, the expression can be derived as:

$$\mathrm{n(r)} = \frac{\mu}{\rho V} \quad (11)$$

Where μ is the material density in μg/m3, ρ is the particle density, V is the volume of the particles in diameter, D.

$$\alpha_m = 169.2 \times \frac{uD^3}{\rho\lambda^4} \left|\frac{\varepsilon - 1}{\varepsilon + 2}\right|^2 \quad (12)$$

Fig. 3.shows the flow of the methodology in determine the haze attenuation in dB/km. By assuming the diameter of the haze particles are 2.5µm and 10µm, the attenuation by haze can be determine based on formula (12).

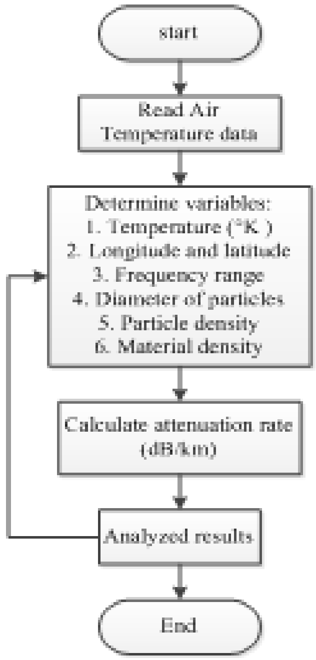

Fig. 3. The flowchart to determine haze attenuation in dB/km

III. FOG ATTENUATION IN ASIAN COUNTRIES

When the surrounding temperature is above 0ºC, the LWC in fog is around 0.5~1.0 g/m3 by using equation showed in (2) [12]. Since, most of Asian countries average temperature is mainly above 0ºC, it can be said that the LWC in Asian countries would be around 0.5~1.0 g/m3. Fog will form when the relative humidity of the surrounding area is high and temperature is low. Therefore, by analyzing the attenuation rate in dB/km, it can determine which of the following Asian countries will be affected more by fog attenuation. As mentioned before, the frequency for millimeter wave started from 24GHz until 100 GHz [13]. However, currently the frequency that had the most international support is 26GHz and 28GHz [14]. Assuming that size of fog particles in all of the selected countries is same, the result can be seen in Fig. 3.

As shown in Fig. 4. (a) and Fig. 4. (b), Malaysia and Qatar will be unlikely to be affected by fog attenuation due to its climate. For Malaysia, the climate is always hot, humid and rainy, meanwhile,

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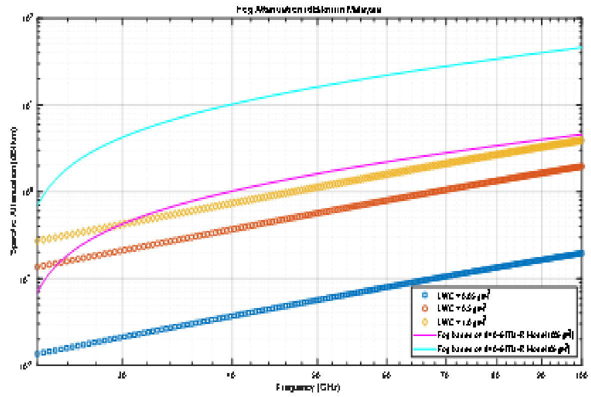
Qatar climates is desert, with very mild winters, and very hot and sunny summers. Both of the countries are located at the tropical region where the temperature mostly reaches around 29~34°C. This is because temperature plays important roles in fog attenuation. The higher the surrounding temperature will lower the attenuation rate. This happen due to the decreasing of the LWC particles.

The fog attenuation can only be affected in Malaysia when the frequency reached above 68GHz and 47GHz for LWC = 0.5 g/m3 and LWC = 1.0 g/m3, respectively. Meanwhile, for country like Qatar fog attenuation can only occurred when the frequency reached above 66GHz and 45GHz for LWC = 0.5 g/m3 and LWC = 1.0 g/m3, respectively.

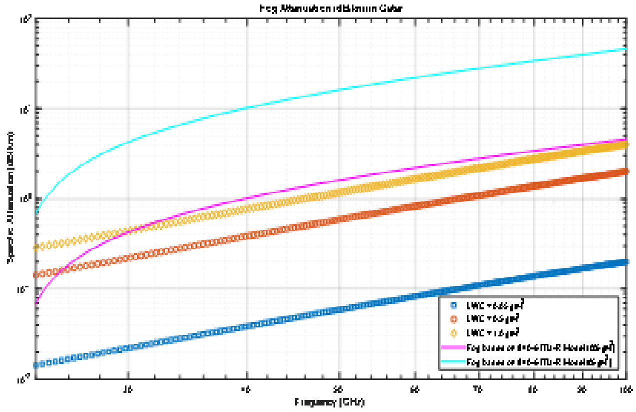
The fog attenuation can only be affected in Malaysia when the frequency reached above 68GHz and 47GHz for LWC = 0.5 g/m3 and LWC = 1.0 g/m3, respectively. Meanwhile, for country like Qatar fog attenuation can only occurred when the frequency reached above 66GHz and 45GHz for LWC = 0.5 g/m3 and LWC = 1.0 g/m3, respectively.

Fig. 4. (c) shows the fog attenuation rate (dB/km) for South Korea. The result shows that chances for South Korea to be affected by fog are higher. This happened because the average temperature for South Korea is around 17°C. South Korea is also located at the temperate region which has moderate temperature. The attenuation caused by fog can affect the millimeter wave in South Korea when the frequencies reaches above 48GHz and 31GHz for LWC = 0.5 g/m3 and LWC = 1.0 g/m3, respectively. Therefore, implementing millimeter wave in Asian countries that have the same climate as South Korea will be quite challenging.

But when the LWC = 0.05 g/m3, the chances for the fog attenuation to happen is lower in every country. However, the possibility of scattering and absorption due to fog with LWC = 0.05 g/m3 also need to be taken into consideration. Table 1 shows the results for fog attenuation in several Asian countries with different LWC. Therefore, it is necessary to consider the attenuation caused by fog in millimeter wave band in Asian countries.



(a)



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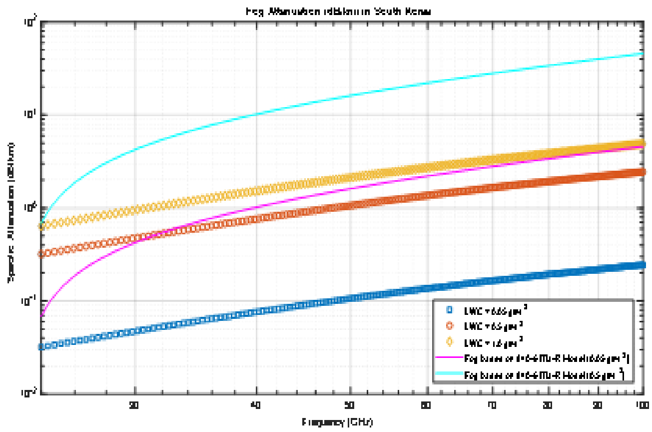

(c)

Fig. 4. (a) The fog attenuation rate (dB/km) in Malaysia; (b) The fog attenuation rate (dB/km) in South Korea; (c) The fog attenuation rate (dB/km) in Qatar

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Table 1. The fog attenuation (db/km) in several asian countries with different lwc (g/m3)

Frequency (GHz)	Fog Attenuation (dB/km) LWC = 0.05g/m^3			LWC = 0.5g/m^3			LWC = 1.0g/m^3		
	Malaysia	Qatar	South Korea	Malaysia	Qatar	South Korea	Malaysia	Qatar	South Korea
24	0.014	0.014	0.03	0.136	0.143	0.320	0.272	0.285	0.641
26*	**0.016**	**0.017**	**0.037**	**0.160**	**0.167**	**0.370**	**0.319**	**0.333**	**0.740**
28*	**0.018**	**0.020**	**0.043**	**0.185**	**0.193**	**0.422**	**0.369**	**0.385**	**0.843**
30	0.021	0.022	0.048	0.211	0.221	0.475	0.423	0.441	0.950
40	0.037	0.039	0.077	0.370	0.385	0.763	0.738	0.769	1.523
50	0.057	0.059	0.107	0.567	0.590	1.065	1.145	1.190	2.146
60	0.080	0.083	0.137	0.798	0.828	1.364	1.605	1.666	2.741
70	0.106	0.110	0.166	1.062	1.099	1.657	2.123	2.197	3.314
80	0.133	0.138	0.193	1.344	1.387	1.930	2.688	2.775	3.860
90	0.165	0.169	0.219	1.645	1.693	2.192	3.290	3.387	4.383
100	0.196	0.201	0.2443	1.961	2.012	2.443	3.921	4.024	4.887

***** Based on the suggested frequency range for millimeter wave by GSMA

IV. HAZE ATTENUATION ON SEVERAL ASIAN COUNTRIES

Major contributors for haze particles are dust and soot particles where it contains 60% in the atmospheric dust. Besides that, the particles of haze can be divided into six categories which are soluble particles, sea salts particles and sulfate particles, insoluble particles, dust particles and soot that had been stated by the International Association of Meteorology and Atmospheric Physics and NASA[15]. However, these particles had been proven to be a liability when it comes to wave propagation. Haze attenuation is caused by the scattering of the wavelength.

Haze can attenuate visible wavelength but hardly can attenuation microwave links [16]. Fig. 5 (a) and (b) show the haze attenuation in selected Asian countries such as Malaysia, South Korea and Qatar with the size of haze particles is 2.5µm and 10µm for PM2.5and PM10, respectively.

From Fig. 5. (a), it can be seen that when the haze particles is 2.5µm the magnitude of particles scattering is 10-11 for millimeter wave in all countries are same whereas it increase as the frequency increase. While, Fig. 5. (b) illustrate the attenuation when haze particles is 10µm with magnitude of particles scattering around 10-9 and increasing as the frequency increase.

This is due to haze do not taken any effect on surrounding air temperature but mainly based on the size of particles and relative humidity. The size of particles is important to determine the scattering of the wavelength. Theoretically, haze will form when the relative humidity is low. But, on equation (12), it only depends on the air temperature alone. Based on the results show that the haze attenuation in millimeter wave is small, however, it cannot be considered negligible in microwave links.

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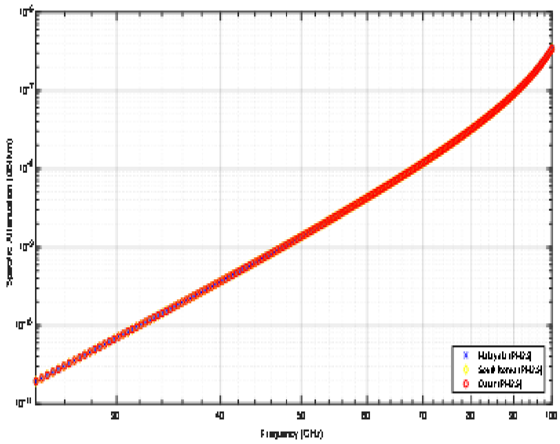
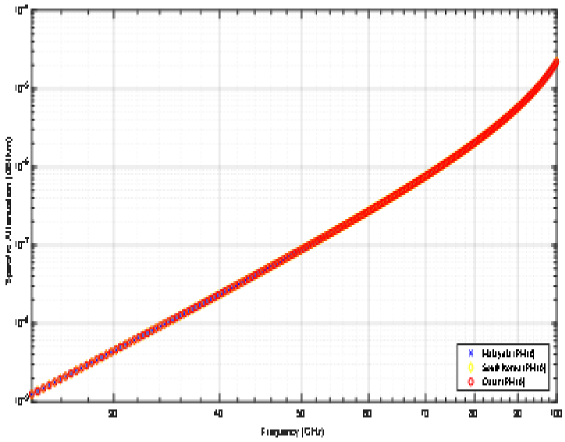


(a)



(b)

Fig. 5. (a) Haze attenuation in several asian countries when haze particles = 2.5µm (PM2.5); (b) Haze attenuation in several asian countries when haze particles = 10µm (PM10)

V. CONCLUSION

In conclusion, there are high possibility of fog and haze attenuation in Asian countries. As the frequency range higher, the attenuation caused by both fog and haze are also increases. Therefore, more researches need to be conducted on fog attenuation in Asian countries. This is because, in every country the values for LWC is different. For fog, the values of LWC is important to determine the attenuation rate in dB/km. Besides that, more concise model need to be developed to determine the effect of haze in millimeter wave. The size of haze particles also plays important roles in determining the attenuation rates in several Asian countries. The bigger the size of particles, the higher the chances of attenuation along the frequency.

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