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Evaluation Of Rain Attenuation Prediction For C, Ku And Ka Frequency Satellite Links In Mongolia By Using ITU-R Propagation Model

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Abstract:
Background: *Satellite communication systems operating at microwave and millimeter-wave frequencies are significantly affected by atmospheric propagation impairments, particularly rain attenuation. As Mongolia plans to launch its national satellite communication infrastructure at the 113.6°E geostationary orbital position, accurate estimation of rain-induced signal degradation becomes essential for reliable link design and system planning.*
Materials and Methods: *This study evaluates rain attenuation for satellite communication links across Mongolia using internationally standardized propagation models recommended by the International Telecommunication Union Radiocommunication Sector (ITU-R). The analysis was performed using ITU-R P.618, P.837, P.838, and P.839 recommendations. Rain attenuation was estimated for representative satellite communication frequency bands including C-band (4-6 GHz), Ku-band (12-18 GHz), and Ka-band (26-40 GHz). Calculations were conducted for the capital city and 21 provincial centers using geodetic coordinates, elevation angles to a geostationary satellite located at 113.6°E, and regional rainfall statistics.*
Results: *The results indicate that rain attenuation strongly depends on operating frequency and regional precipitation characteristics. C-band frequencies experience minimal attenuation, generally below 6 dB across most regions. Ku-band frequencies show moderate attenuation ranging from approximately 2-8 dB, while Ka-band frequencies exhibit significantly higher attenuation levels reaching about 25-27 dB in regions such as Selenge, Uvs, and Dornod. The analysis of attenuation exceeded for different percentages of annual time shows that extreme attenuation events occur during short-duration intense rainfall, particularly at higher frequencies.*
Conclusion: *The findings demonstrate that high-frequency satellite communication systems operating in Mongolia are highly sensitive to rainfall attenuation, especially in the Ka-band. Therefore, sufficient link margins and fade mitigation techniques such as adaptive coding, power control, or site diversity are necessary to ensure reliable satellite communication performance under Mongolian climatic conditions.*
Key Word: *Rain attenuation; Satellite communication; ITU-R propagation model; Radio wave propagation; C-band; Ku-band; Ka frequencies.*

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I. Introduction

Satellite communication systems play an essential role in modern telecommunications by providing reliable communication services over large geographical areas, especially in remote and sparsely populated regions. Compared with terrestrial communication networks, satellite systems require minimal ground infrastructure while providing wide coverage for broadcasting, internet services, and data transmission. However, the propagation of radio waves between a satellite and a ground station is affected by several atmospheric phenomena. Atmospheric gases, clouds, fog, snow, and dust can influence signal propagation, but rainfall is considered one of the most critical factors causing signal attenuation at high frequencies. Rain attenuation occurs when electromagnetic waves interact with raindrops during propagation. The signal energy is partially absorbed and scattered by raindrops, resulting in a reduction in signal strength along the transmission path. This effect becomes particularly significant at frequencies above 10 GHz, which are commonly used in modern satellite communication systems such as Ku and Ka frequencies. The International Telecommunication Union Radiocommunication Sector (ITU-R) has proposed standardized recommendations such as ITU-R P.618, ITU-R P.837, ITU-R P.838, and ITU-R P.839 for predicting rain attenuation under different climatic conditions. These models are widely used in satellite link design, performance analysis, and system planning. Although extensive research has been conducted in tropical and temperate regions, relatively limited studies have focused on rain attenuation in continental climate regions such as Mongolia.

II. Study Area

Mongolia is a landlocked country located in Central Asia between Russia to the north and China to the south. Mongolia covers an area of approximately 1.56 million km² and is characterized by vast geographical diversity, including mountainous regions, steppe grasslands, and desert landscapes. The country lies roughly between latitudes 41°N-52°N and longitudes 87°E-120°E, making it one of the largest sparsely populated countries in the world.The capital city, Ulaanbaatar, located in the north-central part of the country, serves as the main political, economic, and communication center. Mongolia is administratively divided into 21 provinces (aimags) and the capital city. These provinces represent diverse climatic and geographic conditions, ranging from the forested mountainous regions of northern Mongolia to the arid desert areas of the Gobi Desert in the south.

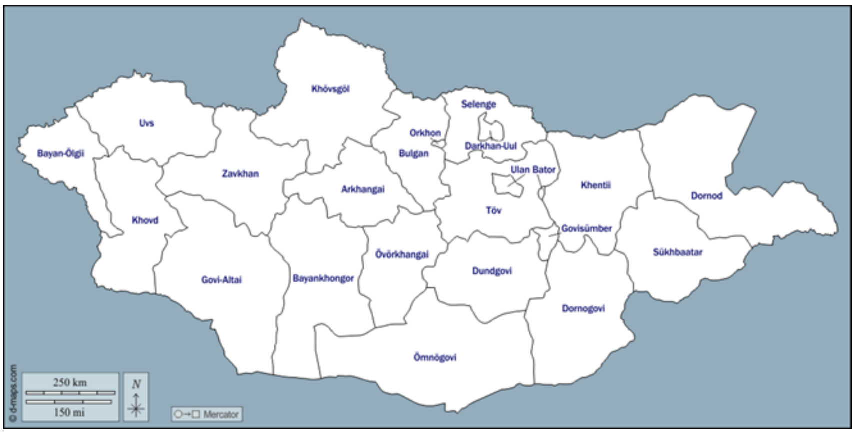

Fig 1. Geography of Mongolia

Consequently, the geographical diversity and varying climatic conditions across Mongolia make it a suitable study region for evaluating rain attenuation characteristics in C, Ku, and Ka band satellite communication links. The large spatial variability in precipitation patterns, ranging from relatively humid northern regions to the arid desert areas in the south, provides an opportunity to analyze the influence of different climatic conditions on satellite signal propagation. In particular, rainfall intensity and seasonal precipitation distribution play an important role in determining the level of signal attenuation at higher frequency bands. Understanding these regional differences is essential for the design and optimization of reliable satellite communication systems operating in Mongolia.

The study area therefore provides a representative environment for investigating rain-induced attenuation using ITU-R propagation models, while also allowing comparison of attenuation characteristics across different climatic zones within the country. Such analyses are important for improving link availability and ensuring stable satellite communication services under varying meteorological conditions.

Rainfall Climatology and Regional Precipitation Characteristics in Mongolia

Mongolia is characterized by a dry continental climate with relatively low annual precipitation. However, a large portion of annual rainfall occurs during short-duration convective storms in summer, which may produce high rainfall intensity and consequently cause significant signal attenuation.

Therefore, investigating rain attenuation under Mongolian climatic conditions is important for designing reliable satellite communication systems. This study aims to evaluate rain-induced attenuation in satellite communication links across Mongolia using ITU-R propagation models and regional rainfall statistics. Also, average annual precipitation characteristics of selected provinces in Mongolia. The data include the long-term average annual precipitation (1999-2021), the average precipitation during the warm season from April to September, its percentage contribution to annual precipitation, and the average annual duration of rainfall events (2020-2022). The provinces are grouped into Central, Northern, Western, Southern, and Eastern regions to illustrate regional variations in precipitation amount and rainfall duration. This is shown in Table 1.

Table 1: Average Annual Precipitation and Rainfall Duration Across Mongolian Regions

Name of city and provinces		Average annual statitcs of 1999-2021			Average annual duration time of precipitation (2020-2024)
		Average annual precipitation [mm]	Average annual precipitation from April to September- [mm]	Average annual precipitation from April to September [%]	Duration time of rainfall [Hours: Minutes: Seconds
Central regions	Ulaanbaatar	251	221	88 %	26:26:36
	Tuv	233	207	89 %	25:45:12
	Uvurkhangai	194	168	86.6 %	28:36:48
	Arkhangai	245	213	87 %	26:40:12
	Bayankhongor	132	114	86.4 %	15:41:24
Northern regions	Selenge	293	256	87.3 %	29:04:24
	Darkhan-Uuk	307	262	85.3 %	18:47:36
	Orkhon	321	277	86.3 %	22:39:24
	Bulgan	283	250	88 %	19:23:12
	Khuvsgul	257	230	89.5 %	25:44:36
Western regions	Govi-Altai	99.4	84	84.5 %	27:19:48
	Zavkhan	174	143	82.2 %	26:04:24
	Uvs	153	123	80 %	23:54:12
	Khovd	95.6	80	83.6 %	21:24:48
	Bayan-Ulgii	116	100.4	86.5 %	28:56:24
Southern regions	Govisumber	145	128	88.3 %	25:49:48
	Dornogovi	115	100.5	87.4 %	21:38:24
	Dundgovi	121	105	86.7 %	22:47:24
	Umnugovi	103	88	85.4 %	26:48:48
Eastern regions	Khentii	255	225	88.2 %	23:52:12
	Sukhbaatar	197	173	87.8 %	26:47:48
	Dornod	242	213	88 %	25:15:48

The data show that precipitation in Mongolia is highly seasonal, with approximately 80–90% of the annual precipitation occurring between April and September in most provinces. The northern and eastern regions generally experience higher annual precipitation compared to the western and southern regions, where the climate is relatively drier. Among the provinces, Orkhon, Darkhan-Uul, and Selenge record the highest average annual precipitation, exceeding 290 mm, while Khovd and Govi-Altai have the lowest values, below 100 mm. In terms of rainfall duration, most provinces experience rainfall events lasting between approximately 18 and 29 hours annually, indicating moderate precipitation frequency. The results highlight clear regional variability in both precipitation amount and rainfall duration

III. Research Methods

Rain attenuation affecting radio wave propagation was estimated using internationally standardized propagation models recommended by the International Telecommunication Union Radiocommunication Sector (ITU-R). In particular, the following recommendations were applied ITU-R P.618-Propagation data and prediction methods for Earth-space telecommunication systems, ITU-R P.838-Specific attenuation model for rain, ITU-R P.837-Rainfall rate statistics, ITU-R P.839-Rain height model. Figure-1 shows a geometric model for calculating the attenuation caused by rain on wave propagation between a space communication ground station and a satellite station.

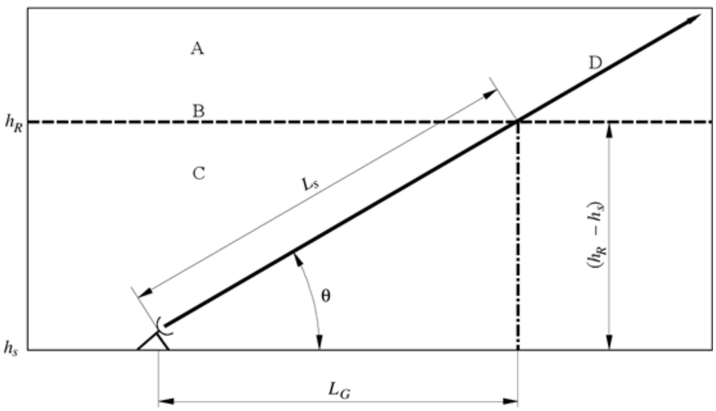

Fig 2. Geometric model of rain attenuation affecting satellite communication links.

The figure illustrates the geometrical model of the Earth–space propagation path used for calculating rain attenuation in satellite communication systems. It shows the relationship between the earth station, the rain layer, and the satellite signal path.

Parameters in the Figure;
- hs-Altitude of the earth station above sea level (m)
- h_R-Rain height, which represents the height of the rain layer in the atmosphere (km)
- θ-Elevation angle of the earth station antenna relative to the horizontal plane (degrees)
- Ls-Slant path length between the earth station and the top of the rain region (km)
- L_G-Horizontal projection of the propagation path within the rain region (km)

The signal transmitted from the earth station antenna propagates toward the satellite along a slant path characterized by the elevation angle. These geometric parameters are essential for estimating rain-induced attenuation in satellite communication links using ITU-R propagation models. The steps required for the analysis are given below:

Step 1: Determine the rain height, H_R as:

$$h_R = h_o + 0.36 \text{ [km]} \quad (2.1)$$

- $h_{(0)}$ is upper atmosphere altitude at which rain is in the transition state between rain and ice. The rain height is defined in km above sea level.

Step 2: Determine the slant path length $L_{(s)}$, below the rain height is given by:

$$L_S = \frac{h_R - h_S}{\sin(\theta)} \text{ [km] for } \theta \geq 5^0 \quad (2.2)$$

Where $h_{(s)}$ (km) is the altitude of Earth station above sea-level and θ (degree) is the elevation angle between the horizontal projection and slant path.

Step 3: The horizontal projection of slant-path length, $L_{(G)}$, (km) is calculated as:

$$L_G = L_S \cos(\theta) \text{ [km]} \quad (2.3)$$

Step 4: Point rainfall rate $R_{(0.01)}$ (mm/h) exceeded for 0.01% of an average year from one-minute integration rain rate data.

Step 5: Obtain the specific attenuation, γ_R-(dB/km) for 0.01 of time as given by:

$$\gamma_R = k * R_{0.01}{}^{\alpha} \text{ [dB/km]} \quad (2.4)$$

Parameters k and α can also be obtained from ITU-R P.838-3

Step 6: The horizontally adjusted path reduction factor $r_{(0.01)}$ for 0.01% of time is given by:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G \gamma_R}{f}} - 0.38(1 - e^{-2L_G})} \quad (2.5)$$

- Where f-(GHz) is the operating frequency, so that the horizontally adjusted rainy slant path length is calculated from:

$$L_R = \frac{L_G r_{0.01}}{\cos\theta} \text{ for } \zeta > \theta \text{ [km]} \quad (2.6)$$

Otherwise,

$$L_R = \frac{h_r - h_s}{\sin\theta}, \text{for } \zeta \leq \theta \text{ [km]} \quad (2.7)$$

$$\zeta = \tan -1 \left(\frac{h_R - h_s}{L_G r_{0.01}}\right) \text{ [degree]} \quad (2.8)$$

Step 7: The vertical reduction factor $r_{(0.01)}$ for 0.01% of time is also given by:

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta[31 - e^{-\left(\frac{\theta}{1} + x\right)}} \sqrt{\frac{L_R \gamma_R}{f^2}} - 0.45]} \quad (2.9)$$

Step 8: Finally, the effective path length L_E (km) through rain is obtained by multiplying the horizontally adjusted slant-path by the vertical reduction factor, as follows:

$$L_E = L_R V_{0.01} \quad (2.10)$$

Step 9: The predicted rain attenuation exceeded for 0.01% of an average year is obtained from:

$$A_R = \gamma_R * L_e \text{ [dB]} \quad (2.11)$$

The above procedure describes the standard method for predicting rain attenuation in Earth–space communication links based on the recommendations of the International Telecommunication Union (ITU-R). The calculation process begins with determining the rain height and the geometric characteristics of the satellite link, including the slant path and its horizontal projection. These parameters define the portion of the propagation path that passes through the rain region. Using the rainfall rate exceeded for 0.01% of an average year, the specific attenuation caused by rain is calculated as a function of rainfall intensity and operating frequency. The horizontal and vertical reduction factors are then applied to account for the non-uniform spatial distribution of rainfall along the propagation path. These factors allow the estimation of the effective path length of the radio signal within the rain layer.

IV. Data Source

To estimate the rain attenuation affecting radio wave propagation of a national satellite system within the territory of Mongolia, calculations were performed for the C, Ku, and Ka frequency bands using fundamental parameters and methodologies based on internationally recognized standards. The calculation incorporates key technical parameters, including rain intensity, statistical distribution of rainfall, average rain height, and the location of the earth station. These parameters are summarized in the table.

Table 2: ITU-R models and input data used for rain attenuation calculation under Mongolian conditions

Parameters	Data	Calculation methods
Satellite position	113.6° E	ITU
Rain intensiry for 0.01% an average year	8 mm/h, 22 mm/h	ITU-R P.893-1
Rain intensiry for 1.0-0.001 % of an average year.	0.1 mm/h-70 mm/h	ITU-R P.837-1
Rain heigth	3 km	ITU-R P.839-3
Polarization	Circular polarization	ITU-R P.838-3
Altitude of earth stations in Mongolian provinces	Capital city and provinces: 619.66 m-2164.24 m	Agency for Land Administration and Geodesy.
Frequencies	C, Ku and Ka	Standard satellite communication frequency bands defined by ITU
Elevation angle of antenna	28°-40°	Calculated from satellite geometric parameters

The basic data and international standard models presented in Table 2 enable a realistic and detailed evaluation of rain-induced attenuation affecting satellite communication signals over the territory of Mongolia.

Satellite Elevation Angle Calculation for 18 Provincial Centers in Mongolia

To evaluate the feasibility of satellite communication links in Mongolia, the geometric parameters between ground stations and a geostationary satellite must be determined. In this study, the elevation angles of earth stations were calculated for all provincial centers across Mongolia assuming a geostationary satellite located at 113.6°E orbital position. The calculations were performed using the geodetic coordinates (latitude and longitude) of each provincial center. Determining the elevation angle is essential for satellite link design, as it directly affects antenna alignment, signal propagation conditions, and potential atmospheric attenuation along the propagation path.

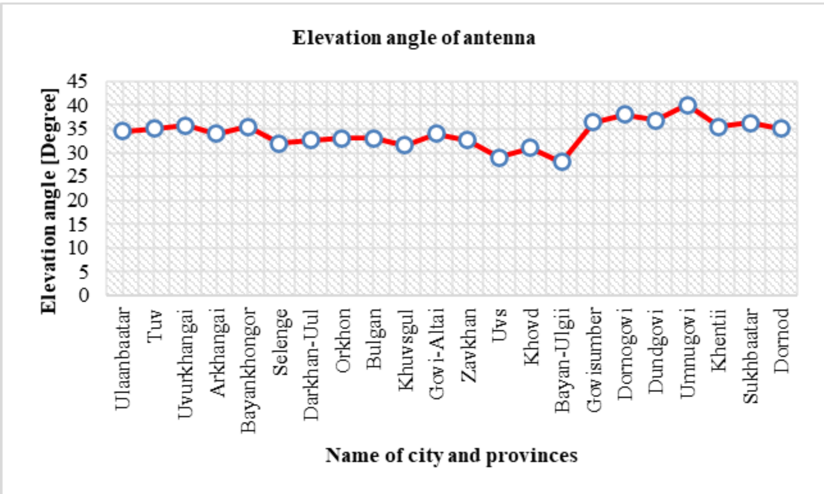

Fig 3. Calculated elevation angles of ground stations in Mongolia for a satellite located at 113.6°E.

The results indicate that the calculated elevation angles for the selected provincial centers generally range between approximately 28° and 40°. Higher elevation angles are observed in the eastern and central regions of Mongolia, while relatively lower values occur in some western locations due to their larger longitudinal separation from the satellite position at 113.6°E. Nevertheless, all calculated elevation angles remain sufficiently high for reliable satellite communication links. These geometric parameters provide a fundamental basis for subsequent analyses of atmospheric attenuation and link budget estimation for satellite communication systems operating in Mongolia.

Study Sites and Altitude Characteristics

Mongolia is characterized by a highly continental climate with significant spatial variations in precipitation and elevation. For this study, the capital city and 21 provincial centers were selected as representative locations across the central, northern, western, southern, and eastern regions of the country. Geodetic coordinates and altitude data for each location were obtained from the national geodetic database provided by the Agency for Land Administration and Geodesy. It is shown in Table 3.

Table 3: I Geodetic coordinates and altitude data

№	**Name of city and provinces**	**Name of places**	**Number of point**	**Altidute [m]**
A	**Central region**			
1	Ulaanbaatar	District of Khan-Uul	ГЦТ 17001142	1428.6
2	Tuv	Zuunmod	GPS-43	1514.2
3	Uvurkhangai	Arvaikheer	ГЦТ-5131	1831.9
4	Arkhangai	Erdenebulgan	ГЦТ-559	1716.2
5	Bayankhongor	Bayankhongor	ГЦТ-3145	1881.2
B	**Nothern region**			
6	Selenge	Sukhbaatar	ГЦТ-1518	619.7
7	Darkhan-Uuk	Darkhan	ГЦТ-5164	713.2
8	Orkhon	Bayan-Undur	PP-13	1337.23
9	Bulgan	Bulgan	ГЦТ-0016	1204.2
10	Khuvsgul	Murun	ГЦТ-5721	1300.8
C	**Western region**			
11	Govi-Altai	Esunbulag	ГЦТ-1047	2164.24
12	Zavkhan	Uliastai	ГЦТ-3665	1755.2
13	Uvs	Ulaangom	ГЦТ-3122	928.5
14	Khovd	Jargalant	ГЦТ-4736	1404.73
15	Bayan-Ulgii	Ulgii	ГЦТ-3311	1714.81
D	**Southern region**			
16	Govisumber	Sumber	ГЦТ-9134	1287.6
17	Dornogovi	Sainshand	ГЦТ-4335	983.9
18	Dundgovi	Saintsagaan	ГЦТ-1051	1426.7
19	Umnugovi	Dalanzadgad	ГЦТ-41-111	1262.66
E	**Eastern region**			
20	Khentii	Kherlen	ГЦТ-11	1030.9
21	Sukhbaatar	Baruun-Urt	ГЦТ-1812	1015.9
22	Dornod	Choibalsan	ГЦТ-5726	713.2

The table summarizes the geodetic reference points and altitudes of selected cities and provinces across Mongolia, which were used as ground station locations in the study. In total, 22 observation points were selected and categorized into five geographical regions: central, northern, western, southern, and eastern Mongolia. These locations represent the main provincial centers and provide a spatially distributed dataset for analyzing satellite communication propagation conditions. The altitude of the selected locations varies significantly, ranging from approximately 619.7 m in Sukhbaatar (Selenge province) to 2164.24 m in Esunbulag (Govi-Altai province) above sea level. The western and central regions generally have higher elevations, reflecting Mongolia's mountainous terrain, while the northern and eastern regions are relatively lower in altitude. These altitude differences are important for satellite communication studies because selected geodetic points provide representative topographical conditions for evaluating rain attenuation and atmospheric effects on satellite communication links across Mongolia.

Global Distribution of Rainfall Rate Exceeded for 0.01% of Time

The global distribution of rainfall intensity zones, which are commonly used in satellite communication studies to estimate rain-induced signal attenuation. These zones are defined according to the rainfall rate exceeded for 0.01% of an average year, as recommended by international propagation models. The color-coded regions represent different levels of rainfall intensity, indicating the spatial variability of precipitation across the world. This classification is developed by the International Telecommunication Union – Radiocommunication Sector (ITU-R) and is widely used in fields such as satellite communication, microwave link design, and climate studies. Rainfall intensity can significantly affect radio signal propagation, especially at high frequencies, causing attenuation and signal degradation. Therefore, the world is divided into several rain zones, labeled from Zone A to Zone P, each representing a different range of rainfall rate measured in millimeters per hour (mm/hr). Lighter colors indicate regions with lower rainfall intensity, while darker colors represent areas with heavier and more frequent rainfall. Such classification is essential for predicting the impact of rain on radio wave propagation, particularly for Earth-space communication links operating at microwave and millimeter-wave frequencies.

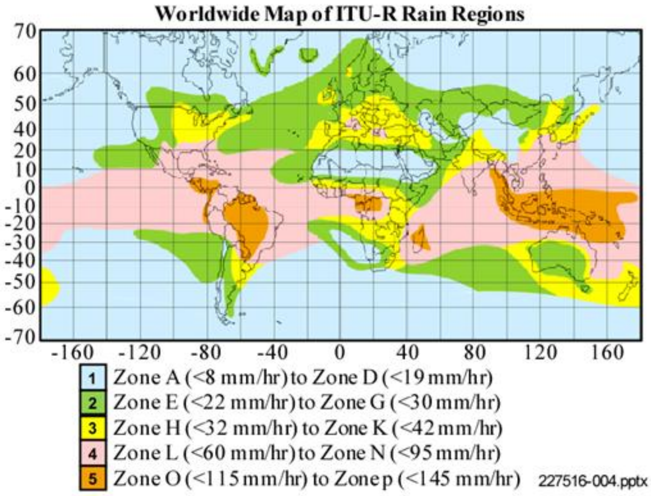

Fig 4. Global worldwide map of ITU-R rain regions Rainfall Intensity Distribution

According to the map, Mongolia is mainly located within the green-colored region, which corresponds approximately to Zone A and Zone E. This classification reflects Mongolia's continental climate, where precipitation levels are generally moderate to low compared with tropical regions. Most rainfall occurs during the summer months, while the rest of the year is relatively dry. Because Mongolia lies far from oceans and is dominated by steppe and semi-arid landscapes, extreme rainfall events are less frequent than in tropical or monsoon regions. Also ITU-R P.837 recommendation provides a global method for estimating rainfall rate statistics that are important for radio communication system design. It is mainly used in satellite and terrestrial microwave link planning because rainfall can cause rain attenuation, which weakens radio signals, especially at high frequencies (above about 10 GHz). It is shown in Table 4

Table 4: Rain Rate Distribution by Percentage of Time for ITU-R Rain Zones A–Q

Percentage of time	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.0	01	05	07	21	06	1.7	3	2	8	15	2	4	5	12	24
0.3	08	2	28	45	24	45	7	4	13	42	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

In table shows rainfall rates for different rain climatic zones (A–Q) and for different time percentages. Each zone represents a region with similar rainfall characteristics. Higher zone letters (such as P or Q) correspond to very heavy rainfall regions, usually found in tropical climates, while lower zones (A–D) represent drier regions with lighter rainfall. In practice, ITU-R P.837 helps engineers estimate the expected rainfall intensity at a specific location and determine how much signal fading due to rain might occur, allowing them to design more reliable communication systems.

V. Result

Estimated result of rain attenuation for satellite communication links across different regions of Mongolia for multiple frequency bands used in C, Ku, and Ka-band satellite systems. The attenuation values were evaluated for frequencies of 4, 6, 12, 18, 26, and 40 GHz, representing typical downlink and uplink operating bands. The results show clear regional variability in rain attenuation and demonstrate the strong dependence of attenuation on operating frequency.

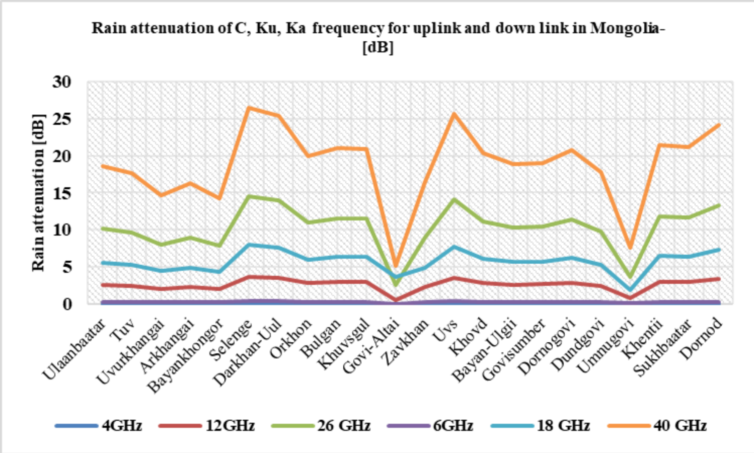

Fig 5. Estimated rain attenuation for satellite uplink and downlink frequencies (4–40 GHz) in different regions of Mongolia.

The analysis indicates that rain attenuation increases significantly with frequency. In particular, the Ka-band frequencies (26-40 GHz) exhibit the highest attenuation levels, reaching approximately 25-27 dB in regions such as Selenge, Uvs, and Dornod. In contrast, lower frequency bands such as C-band (4-6 GHz) experience minimal attenuation, generally remaining below 6 dB across most regions. Moderate attenuation levels are observed in the Ku-band frequencies (12-18 GHz), where attenuation typically ranges between 2 and 8 dB depending on regional precipitation characteristics. Spatial variability is also evident across Mongolia, with higher attenuation values generally observed in northern and eastern regions where precipitation intensity is relatively higher. These results highlight that while C-band systems provide higher link reliability under rainy conditions, Ka-band satellite systems operating in Mongolia require appropriate fade mitigation techniques such as adaptive coding and modulation, power control, or site diversity to maintain link availability.

Also, we estimated rain attenuation for different percentages of annual time (1%, 0.1%, 0.01%, and 0.001%) across the main geographical regions of Mongolia. The results are shown for representative satellite communication frequencies of 6 GHz, 18 GHz, and 40 GHz, corresponding to C-, Ku-, and Ka-band systems. This comparison highlights the combined influence of frequency and time availability on rain-induced attenuation in satellite communication links.

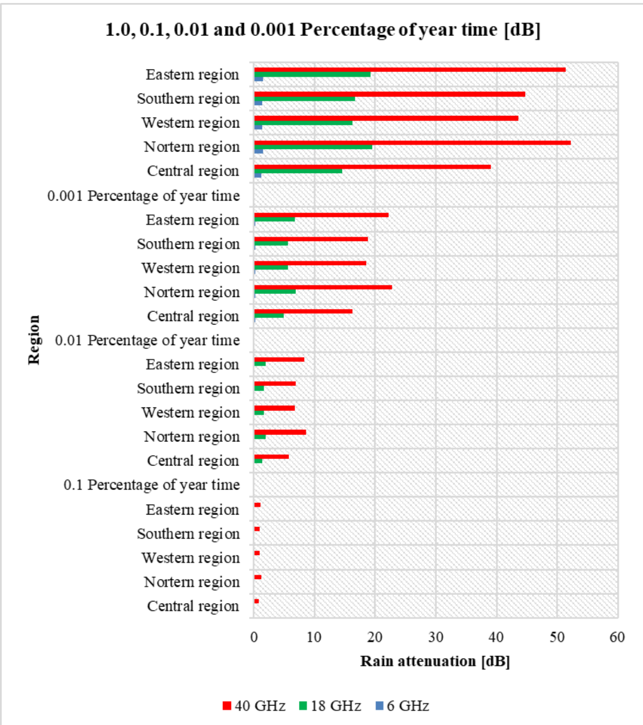

Fig 6. Rain attenuation exceeded for different percentages of annual time (1%, 0.1%, 0.01%, and 0.001%) in regions of Mongolia

The results demonstrate that rain attenuation increases significantly as the percentage of time decreases, indicating that extreme attenuation events occur during short-duration but intense rainfall conditions. At the lowest exceedance probability of 0.001% of the year, attenuation values reach the highest levels, particularly at higher frequencies. For example, at 40 GHz the attenuation exceeds approximately 50 dB in the northern and eastern regions, while lower frequency bands such as 6 GHz experience negligible attenuation across all regions. At moderate frequencies such as 18 GHz, attenuation values remain within a moderate range but still show clear regional variation. In general, the eastern and northern regions exhibit slightly higher attenuation levels compared to the central and southern regions, reflecting differences in precipitation characteristics. Overall, the results confirm that higher frequency satellite systems, especially those operating in the Ka-band, are significantly more sensitive to rainfall attenuation and therefore require appropriate link margin and fade mitigation techniques to ensure reliable satellite communication performance in Mongolia.

VI. Conclusion

This study analyzed rain attenuation affecting satellite communication links in Mongolia using ITU-R propagation models for representative C-, Ku-, and Ka-band frequencies. The results show a strong dependence of attenuation on operating frequency, where C-band frequencies experience minimal attenuation, Ku-band frequencies exhibit moderate attenuation, and Ka-band frequencies show significantly higher attenuation levels. Regional analysis indicates that northern and eastern parts of Mongolia generally experience higher attenuation due to relatively greater precipitation compared with the central and southern regions.

The evaluation of attenuation exceeded for different annual time percentages (1%, 0.1%, 0.01%, and 0.001%) further demonstrates that extreme attenuation events occur during short-duration but intense rainfall periods. At 40 GHz, attenuation may exceed 50 dB at very low exceedance probabilities. These findings highlight the importance of incorporating sufficient link margin and fade mitigation techniques when designing high-frequency satellite communication systems in Mongolia.

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