Performance Analysis and Optimization of HF Communication Over Bangladesh

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Abstract— Solar activity has a significant impact on the ionosphere, which can lead to adverse effects on the performance of high-frequency (HF) communication systems. Solar discharges cause expanded ionization, resulting in signal propagation that can cause disturbances. During a solar maximum, the ionosphere experiences even more dramatic changes due to the increased solar emissions, such as coronal mass discharges and solar flares. The ionosphere is ionized by solar radiation from the Sun, producing free electrons and ions, which can be measured through Total Electron Content (TEC) observations. TEC observations have become an essential tool for understanding the ionosphere's structure and variations. The relationship between solar activity and the ionosphere is complex and dynamic, requiring ongoing research and monitoring to improve our understanding and predict potential impacts on high-frequency communication systems. By understanding the effects of solar activity on the ionosphere, we can better mitigate the risks to these systems and ensure their continued operation. This investigation led us to a better analysis of HF communication from the perspective of Bangladesh. Maximum usable frequency (MUF) is taken into the consideration for improving the performance of HF propagation. So that four different locations were used to take data that represents all the major parts of the country. In this context, TEC observations play a critical role in helping us to comprehend the ionosphere's behavior and the effects of solar activity on it over Bangladesh.

Keywords— High frequency (HF), Total Electron Content (TEC), Maximum Usable Frequency (MUF), Communications Security (COMSEC), Global Ionosphere Maps (GIMs), Modified Single Layer Model (MSLM), Vertical Total Electron Content (VTEC)

I. INTRODUCTION

High-frequency (HF) radio communication is a crucial component of modern communication infrastructure. The range of electromagnetic waves between 3 to 30 MHz is classified as HF [1]. This frequency band is a significant part of the shortwave frequency range and is known as shortwave radio.

HF radio signals are reflected Earth by the ionosphere layer in the atmosphere [2], resulting in "skip" or skywave propagation. This makes it an ideal choice for long-distance communication and is used for intercontinental distances. The Total Electron Content (TEC) is an important factor in describing the propagation of HF signals and is the measurement of whether the signal will be refracted to the ionospheric layer or cross the ionosphere. Frequencies below 3 MHz will not reach the ionosphere, while frequencies above 30 MHz will cross the ionosphere and will not be refracted back [3].

There are two types of space waves, direct component, and aground-refuted component. For HF signal propagation, the direct component is considered while the ground-reflected component terminates at a close distance. HF antennas are typically omnidirectional, and the signal acts as a straight propagating wave line [4]. The frequency affects the absorption and jump distance, with higher frequencies resulting in lower absorption and larger jumps. TEC varies with the atmosphere and indicates successful propagation.

HF frequencies are used for a variety of purposes, including international shortwave broadcasting stations (2.310 - 25.820 MHz), aviation communication, government time stations, weather stations, amateur radio, and citizen band services, among others [5]. It is the highest effective frequency that can be used for communication for 90% of the days of the month, making it a reliable option. However, the absence of base or mobile stations for backup makes communication in case of an emergency virtually impossible.

HF radio link provides a reliable communication link in the worst possible situation even. The combination of HF and VHF on a communications network increases coverage strength by providing VHF Press-to-talk communications for short-range transmission and HF over long distances [6]. This provides a clear benefit over satellite communications, as it offers both audio clarity and secure AES 256 encryption for voice traffic, allowing operators to freely discuss operational matters without fear of breaching communication security (COMSEC).

Another attractive aspect of HF is its ability to offer Occupational Health and safety compliance through GPS location services for deployed personnel operating in remote areas. This is a clear advantage over satellite services and adds an extra layer of safety for personnel working in hazardous environments. In conclusion, HF radio communication is a crucial component of today's communication infrastructure and offers a reliable and secure option for long-distance communication. Its combination with VHF provides increased coverage and its use of GPS location services adds an extra layer of safety for personnel operating in remote areas.

The MUF and Delay curves were calculated for five specific frequencies for which differences in the behavior of HF signal were studied. The findings of this investigation will lead us to the highest efficient communication link using HF signals. Moreover the Satellite-based internet system if HF technology can be introduced the cost of the whole system will lesser.

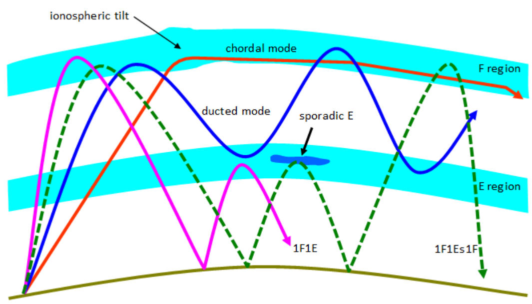

Fig. 1. HF Communication link

II. Literature Review

The effectiveness of HF communication is heavily influenced by various signal parameters, including MUF, ionospheric delay, and TEC. In this literature review, we explore various studies and finding methods that investigate these parameters in HF communication. In literature, various models and techniques have been proposed for TEC calculation, such as the Global Ionosphere Maps (GIMs)[7] , the Klobuchar model, and the NeQuick model. For ionospheric delay calculation, the most commonly used models are the Modified Single Layer Model (MSLM) and the Vertical Total Electron Content (VTEC) [8] model. These models can be used to estimate the ionospheric delay based on TEC and other ionospheric parameters. Ionospheric delay is another contribution to HF communication. It has an effective impact on HF communication. Various authors suggested many methods for calculating ionospheric delay including the Dual-Frequency Method, Single-Frequency Method, Global Ionospheric Maps, and the Klobuchar Model[9]. These methods differ in their approach and level of aaccuracy Similar goes for MUF, it can be calculated using various methods, including the CCIR method, Smith’s formula, ITU-R P.533 method, and Tucnak’s model. These methods estimate MUF based on ionospheric models, electron density profiles, and solar activity, among other factors.

III. Methodology

Firstly, we collect the TEC data to analyze the HF performance. This TEC has an effective impact on ionospheric delay calculation. And ionospheric delay influences HF communication by causing signal blurring, multi-way proliferation, and expanded signal spread time, prompting decreased signal strength, expanded mistakes, and expanded dormancy. Next, selected MUF as our parameter of HF communication which will ensure reliable long-distance communication.

In summary, TEC, ionospheric delay, and MUF are parameters that impact the reliability of HF communication. Understanding and taking these parameters into account can help ensure successful and effective communication using HF.

A. TEC Calculation

The impact of TEC on HF communication can be significant as TEC affects the propagation of radio signals through the Earth's ionosphere. High TEC values can lead to increased ionosphere absorption and scattering, causing signal degradation or loss. Conversely, low TEC values can improve signal propagation and increase the effective range of HF communication [10]. Thus, monitoring TEC can help to optimize HF communication systems and mitigate the impact of adverse ionospheric conditions.

Measuring TEC, either directly or indirectly, can provide information about the ionospheric delay and its impact on radio wave propagation.

We calculate TEC data by Trimble GNSS software where it calculates the TEC using equation 1

$$TEC = \frac{40.3}{f^2} * 10^{16} \qquad (1)$$

Where f is the frequency range of HF communication. From the main location Dhaka to 4 different locations Teknaf, Sylhet, and Khulna have less distinguishable variations of TEC value. Hera TEC is calculated using the different frequency ranges of the

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HF communication band. For example, we have used 3-30MHz. From this variation of TEC, an ionospheric frequency delay occurs which degrades the performance of HF Communication in Bangladesh.

B. MUF Calculation

The MUF in HF communication refers to the highest frequency that a radio signal can travel between two points without being reflected on the earth's surface [11]. It is affected by several factors, including the state of the ionosphere, solar activity, the time of day, and the season. If the frequency of a transmitted signal is higher than the MUF, it is likely to be reflected on earth, reducing the range and quality of communication [12]. Therefore, the MUF is an important factor to consider when choosing the frequency for HF communication to ensure reliable long-distance communication.

$$MUF = \frac{\textbf{Critical frequency}}{\cos\Theta} \quad (2)$$

Where critical frequency is considered as our HF frequency range values and Θ is the angle of incident. We have also calculated the MUF value from Dhaka to four different locations by VOACAP software. Here in this software, the frequencies were used within HF frequency range value. This shows that in long-range HF communication, the percentages of successful communication establish on the different frequency ranges.

C. Ionospheric Delay

Ionospheric delay is a phenomenon where radio waves traveling through the Earth's ionosphere are refracted, causing a delay in their arrival time. This can affect HF communications by causing signal fading, multi-path propagation, and increased signal propagation time, leading to reduced signal strength, increased errors, and increased latency [13]. The impact of ionospheric delay on HF communication can vary greatly depending on the time of day, solar activity, and other factors.

The ionospheric delay is directly related to the TEC of the ionosphere. The TEC along the path of a radio wave determines the amount of refraction that the wave will experience, and hence the total ionospheric delay. Higher TEC values result in more refraction and a greater ionospheric delay, while lower TEC values result in less refraction and a smaller ionospheric delay. Using the Klobuchar model, we can optimize the Frequency range with obtained TEC data.

$$I_g = \frac{40.3}{f^2} * TEC \quad (3)$$

Where f is the best frequency obtained using the TEC value in the model equation.

IV. Data Analysis And Outcome

A. TEC Data Plotting

From the main location Dhaka to 4 different locations Tetulia, Teknaf, Sylhet, and Khulna have less distinguishable variations of TEC value. So that the data we get considered all over the Bangladesh data and according to the data we find the curves are shown in Figure 2.

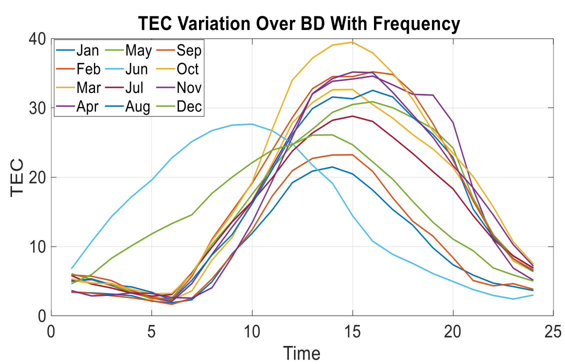

Fig. 2. TEC Vs Time Over Bangladesh

Here the curve shows the TEC vs Time plot for the Bangladeshi region of the whole year 2021 showing one month interval. The plots are not uniform as the TEC changes with the change of various activities of atmosphere and Solar activities.

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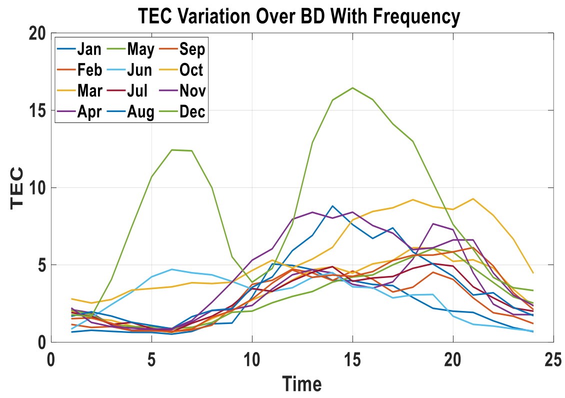

Fig. 3. TEC Vs Time Over Bangladesh in Standard Deviation

B. Ionospheric Delay Plotting

From the TEC value over Bangladesh, we calculate the ionospheric delay from the equation. This delay value defines for which frequency and TEC value delay is more. If the ionospheric delay is more than HF performance is lower in range or vice versa. So, dividing the HF range from 3-30MHz in 5 intervals, we get 3,8,13,18,23,28 MHz values which are used in delay calculation, and total TEC data for 12 months gives us this delay curve:

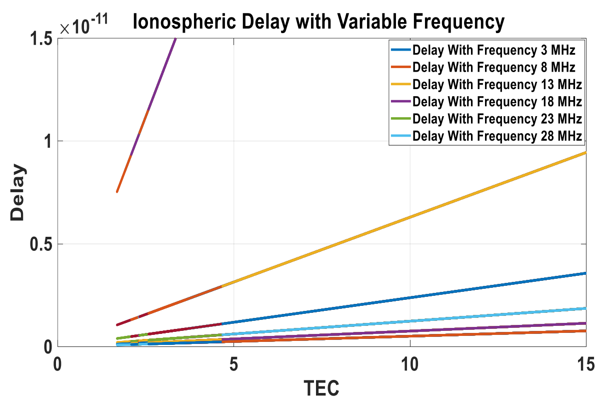

Fig. 4. Delay vs TEC Curve

Figure 4 shows the Delay vs TEC curve of the locations for six different frequency ranges.

C. MUF Data Plotting

MUF data for our four different locations over Bangladesh shown at the graphs below.

- For Dhaka to Tetulia (26.5197 : 88.4125):

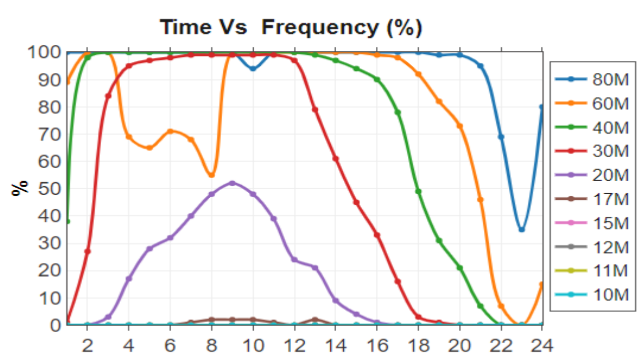

Fig. 5. Time vs Frequency plotting for Dhaka to Tetulia

- For Dhaka to Teknaf (20.8639 : 92.3126):

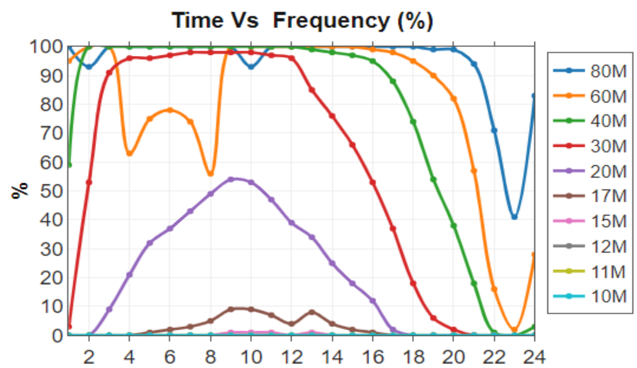

Fig. 6. Time vs Frequency plotting for Dhaka to Teknaf.

- For Dhaka to Khulna(22.2077 : 89.4287):

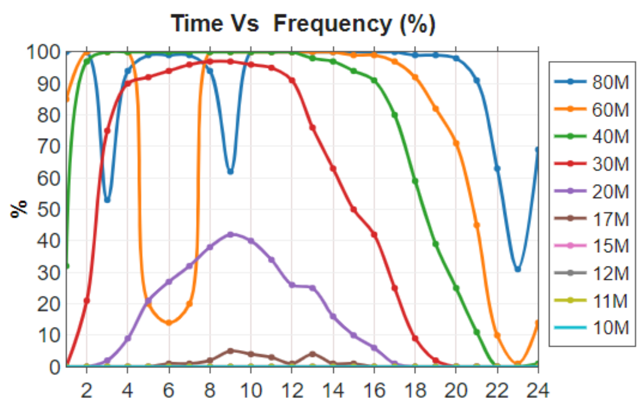

Fig. 7. Time vs Frequency plotting for Dhaka to Khulna

- For Dhaka to Sylhet (24.8466 : 91.8567):

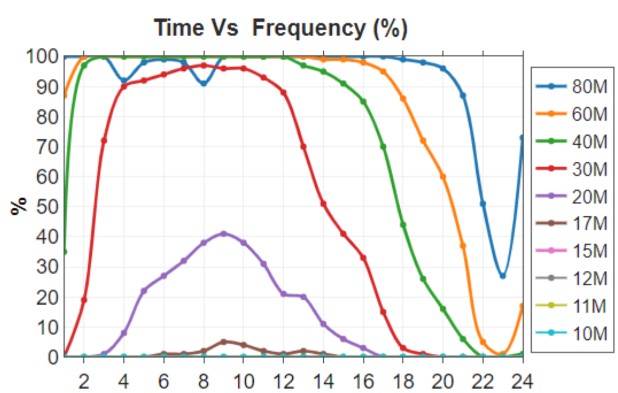

Fig. 8. Time vs Frequency plotting for Dhaka to Sylhet.

Here Figure 5 to 8 shows the Time vs Frequency plots for four locations Tetulia, Teknaf, Khulna and Sylhet from Dhaka (23.7552:90.3957) respectively. During our investigation, we considered these 4 different locations for carrying out the measurement.

V. RESULT ANALYSIS AND OUTCOME

From the above investigation, we have identified that the ionospheric effect delay is significant for HF communication.

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Our main goal was to analyze the performance of HF communication in the region of Bangladesh. So we evaluated some of the parameters which affect HF communication. Mainly we focused on the TEC which affects the ionospheric delay and maximum usable frequency. All the observations are shown below:

When the TEC increases the ionospheric delay increases. Figure. 4 shows this relation in a precise form. From the observation, it is found that when TEC is 2.5 the delay is 0.1ps and with the increase in TEC when TEC is 40 the delay decreases to 1.8ps.

Here from figures 5 to 8, it can be obtained that when the frequency is lower in range the signal is traveling to the highest distance. Besides, it is also to be noted that after crossing a certain range of HF the signal is not appearing in the curve because high-range frequency propagation is less. We can see after 17 meters (18.06 – 19.02) MHz range are hardly can propagate for long distance. The reason is clear that the signals are crossing the Ionosphere region and are not refracting back.

The TEC changes with the course of time, from Figure 2 and 3 it can be understood where at the case of Bangladesh a country in the north polar region from the tropic of cancer in the winter season the TEC value is comparatively lower than in the summer season. For example, the **highest** TEC was found from the tests are at the month of **October** and the **lowest** was found in **January**. This helps in terms to understand the next probable communication activities of HF as its range can be forecasted earlier.

Here at our investigation, the 6 frequencies used were 3,8,13,18,23 and 28MHz. The delay plot shows that the lower frequencies of this range like 3 to 13 MHz can't sum up a huge difference at the delay curve but the 23 and 28 MHz frequency has a great impact on the delay curve. So it can be summed up that at lower frequencies the HF has the least effect to be shown.

VI. Conclusion And Future Aspects

In conclusion, we can say that TEC has the lion's share in the improvement and degradation of HF communication. There are many factors also by which HF communication performance will be varied like a few atmospheric effects, rains, tornadoes, an increase in the number of solar flares, etc. In this paper, we showed how TEC and MUF are affecting our region's HF communication by calculating their delay curves. From the Ionospheric delay calculation, we clearly figured out when our frequency will be in the high range and vice versa for better HF communication at different parts of the year. According to the delay calculation, we can suggest when the TEC value is less in winter at that time HF performance is better than other periods of the year. A few other important parameters are also there like Solar flares, Sunspot numbers, etc on which further research can be done. Here we considered only one year for our research. In this paper, we worked with very less no of HF communication factors. For more better performance increasing the number of years data will provide more precise analysis of HF communication over Bangladesh.

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