The 4G Network Traffic Performance under Natural Lightning Electromagnetic Interference

Antony Sumardi[a], Mohd Riduan Ahmad[a], Shamsul Ammar Shamsul Baharin[a], Muhammad Haziq Mohammad Sabri[a] Mohamad Zoinol Abidin Abd Aziz[a], Norbayah Yusop[a], Imran Mohd Ibrahim[a], Mardina Abdullah[b]

[a]Centre of Technology for Disaster Risk Reduction, Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[b]Space Science Centre (ANGKASA), Institute of Climate Change (IPI), Universiti Kebangsaan Malaysia (UKM), Bangi 43600, Selangor, Malaysia.

Abstract

This study investigates the impact of lightning electromagnetic interference on The Fourth Generation Long Term Evolution (4G LTE) network performance focusing on the 2.3 GHz frequency band commonly used by mobile communication networks. Experiments have been conducted to measure the effects of lightning electromagnetic interference on 4G data transmissions at Melaka, Malaysia by using few measurement tools and open-source software. An Internet Performance Working Group Third Version (Iperf3) was used to generate network traffic for the network performances. The performance evaluation of Transmission Control Protocol (TCP) focused on the throughput log files. The electric field mill (EFM) and Constant Altitude Plan Position Indicator (CAPPI) radar data were collected to observe the background electric field and validate the existence of thunderclouds. On the other hand, a fast electric field buffer circuit was used to determine the type of lightning flashes captured. After the measurement campaign, 2 storms have been analysed where the correlation between flash rate, EFM value, throughput and reflectivity index are involved. The first and second storms recorded multiple drops of throughput during lightning activity occurred and on the other hand also showing a fluctuation without the appearances of lightning. This experiment result could be become the pioneer to mitigation strategies for network protocol used and contribute to the development of network performance.

1 INTRODUCTION

Throughout the field of lightning studies, previous studies have thoroughly investigated a variety of lightning occurrences and the mechanisms behind them. These studies reveal that lightning behaves throughout a wide range of frequencies, from incredibly high to remarkably low frequencies [1], [2], [3], [4], and [5]. This becomes especially important when it comes to wireless communication, as the frequencies used for operation occasionally coincide with the lightning spectrum. As a result of these two phenomena sharing frequency bands, there is a substantial chance that they may interact with each other.

The pioneer experiment that works on the interference from the natural phenomena were done by [6], they were using a pair of walkie talkie with multiple channel and nodes where it operates on a range of 300 megahertz to 3 gigahertz and the experiment revealed that the system had experienced data loss and error from the receiving part depending on the current values and lightning conditions.

Next, the experiment conducted in [7] is the continuous research on previous study. The wireless fidelity (Wi-Fi) at 2.4 GHz frequency and user datagram protocol (UDP) were employed in the experiment. From the result, a high bit error rates and burst error events occurred during the presence of lightning. In this experiment the wireless communication does have the interference from lightning. The most powerful type of lightning that causes the interference to the wireless communication systems were found to be narrow bipolar events (NBEs).

Additionally, [8] conducted a different investigation that examined The Fourth Generation Long Term Evolution (4G LTE) mobile connection communication domain and found instances of 2.3 GHz frequency band interference disturbance. These results highlight how important it is to deal with any possible interference problems in this frequency band.

Finally, the disruptive effect of natural lightning on mobile communication data transmission was found in a follow-up investigation that used UDP and a 2.3 GHz mobile connection. The analysis uncovered cases of interference that caused interruptions and throughput reductions, which were most noticeable during thunderstorms. Notably, the main sources of interference were found to be lightning flashes that occurred from the cloud-to-ground (CG) and cloud flash known as intra-cloud (IC) [9].

In this paper, inspired by the pioneering work of [6], [7], [8], and [9] we conduct an experiment to assess lightning interference on 4G LTE communication links using a different protocol which is Transmission Control Protocol (TCP) as the primary internet protocol. Through this study, our objective is to evaluate performance in terms of throughput and explore the distinct impact compared to alternative network protocols.

978-3-8007-6416-7/24/$31.00 ©2024 IEEE

2 METHODOLOGY

2.1 Electric Field Measurement System

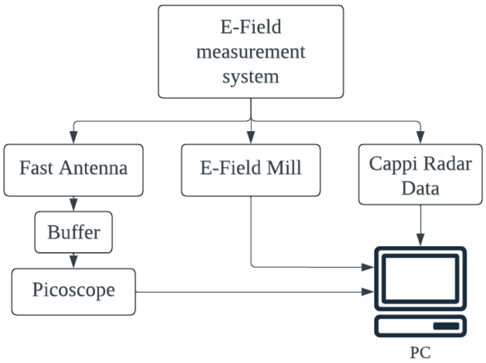

Figure 1: Electric field measurement setup

The electric field measurement system, conducted at the Faculty of Electronics and Computer Technology and Engineering (FTKEK) (UTeM, 2.314077°N, 102.318282°E), consists of three main components. Firstly, a fast antenna (FA) functions as a parallel plate antenna connected to a buffer circuit with a decay time constant of 13 ms, acting as a filter. The collected data is then processed and input into a PicoScope, a PC-based oscilloscope used for measurements, as depicted in **Figure 1**. The PicoScope visually displays the waveform in relation to voltage and time, utilizing the computing power of a personal computer. When the FA sensor is configured with a trigger level of -7 V, it effectively covers an area within a radius of 10 to 30 kilometers [5].
Furthermore, an electric field mill (EFM) is utilized. This sensor is strategically positioned to record the background electric field within a 30 km radius around the designated measurement station. The EFM results are stored in a text file, documenting the electric field's strength every second. Additionally, radar data from the Malaysian Meteorological Department (MMD) website, obtained through the constant altitude plan position indicator (CAPPI), adds a significant dimension to the project. This radar data provides valuable information about atmospheric conditions, enhancing our understanding of the electric field dynamics in the selected geographic area [10].

2.2 Network Performance System

The evaluation of data transmission performance using TCP over 4G LTE operating at 2.3 GHz was conducted using several tools. The primary tool, Internet Performance Working Group Third Version (Iperf3), generated traffic between client and server nodes by delivering packets over a predetermined time interval. It was utilized in the test measures to assess network performance. Wireshark, a comprehensive network protocol analyzer, was employed to verify and observe packet transmission. To enhance the experiment's security and integrity, a VPN connection was also established. **Figure 2** illustrates the network performance configuration setup for this analysis.

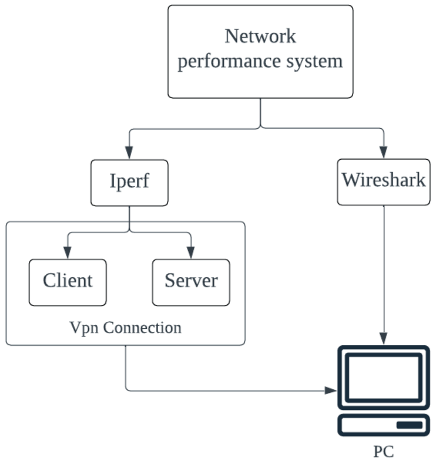

Figure 2: Network performance setup

Iperf3 operates by generating packets transferred from a server to a client, utilizing the Transmission Control Protocol (TCP) in the context of this experiment. A crucial aspect of this process is that each packet is acknowledged before subsequent transmissions occur. To delve deeper into the intricacies of this transfer, Wireshark can be employed, allowing us to verify and analyze the entire communication workflow.

3 Result and Discussion

Table 1: The details of fair-weather and storms selected for the analysis.

Storm	Date	Time
1	2/12/2022	15:10:00 – 19:00:00
2	5/12/2022	10:20:00 – 00:00:00

Figure 3 displays a lightning event that occurred on 2 December 2022. The horizontal axis represents the timeline, while the vertical axis represents the respective data values. The green line represents the index reflectivity, ranging from 55 dBz to 37 dBz. The purple and blue lines represent the throughput graph, with the highest peaks at 4.2k and 4k, respectively. The red line represents the EFM values, reaching a peak from 4.14 kV/m to -3.45 kV/m. Lastly, the bar graph illustrates the captured lightning data from the fast field antenna, denoted as +NBE, -CG, and IC, respectively, in grey, orange, and light blue. The total of 29 lightning with the highest -CG followed by IC and +NBE with the frequency of 17, 7 and 5 respectively.
The fluctuations and patterns observed in the red line, along with the flash rate between 15:00:00 and 15:40:00, indicate a relationship between these two variables. This correlation is further supported by the index reflectivity values within the same time frame. During the time of 15:34:23 and 15:34:34 for the througput client and server respectively, it has reach 0 bit per second where there is also has a recorded flash rate at the time interval. However, during the time where flash rate not captured and the EFM values are at low, there is a temporary drop in throughput

for both the client and server, reaching 0 bit per second for 4 seconds. This drop occured with and without the lightning appearances which demonstrates that the network remains the same overall.

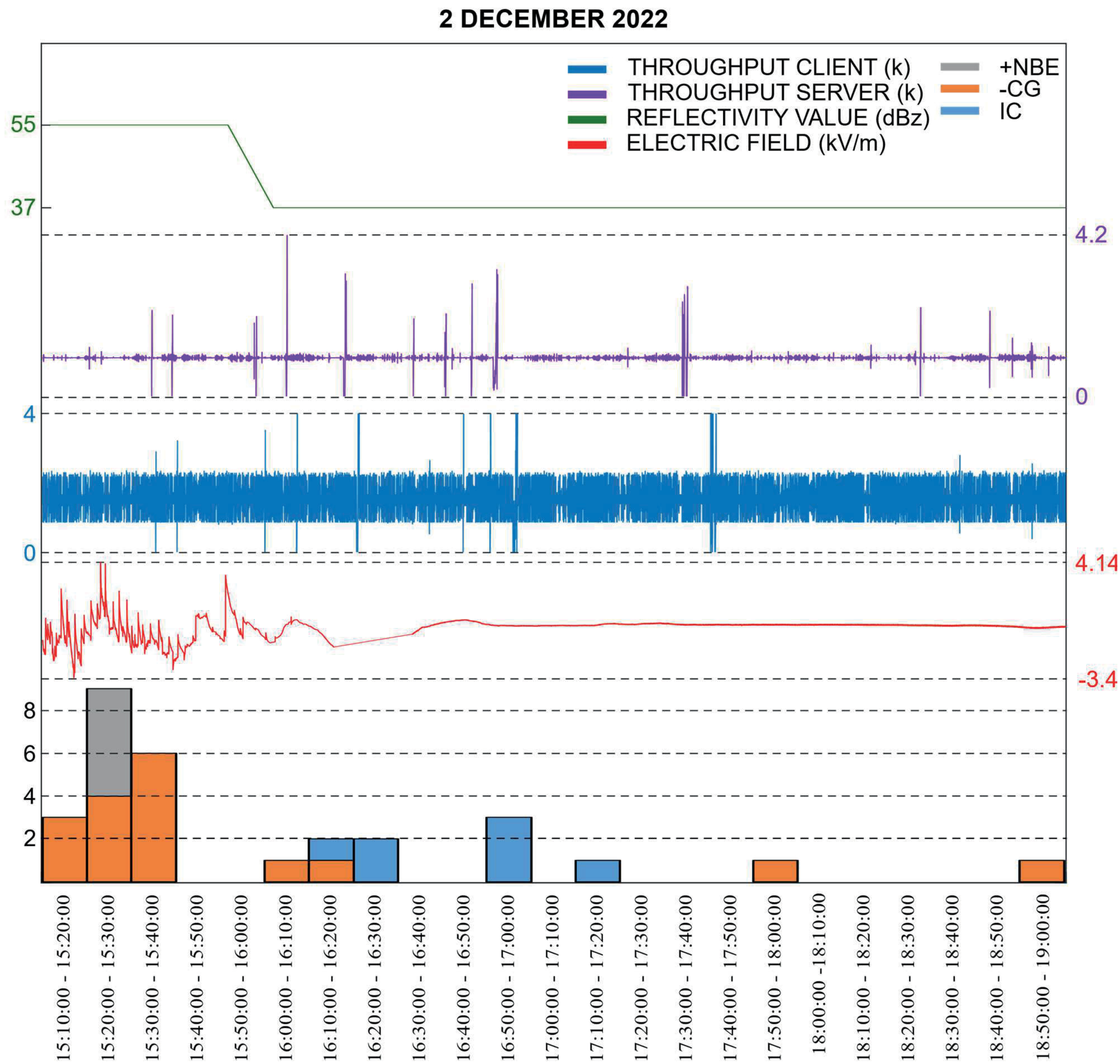

Figure 3: The stacked column bar graphs is samples takens for every 10 minutes for the flash rate on 2 December 2022, from 15:10:00 to 19:00:00. Plotting of the server and client node's throughput is in purple and blue respectively. The red color plot is the background electric field, expressed in kV/m. The green plot is reflectivity value in dBz unit value.

The **Figure 4** illustrates the outcome of a lightning event that occurred on 5 December 2022. The horizontal axis represents the timeline, while the vertical axis represents the respective data values. The green line represents the index reflectivity, ranging from 55 dBz to 12 dBz. The purple and blue lines depict the throughput graph, with the highest peaks at 2.2k and 6.7k, respectively. The red line represents the EFM values, reaching a peak from 4.12 kV/m to -4.23 kV/m. Lastly, the bar graph represents the captured lightning data from the fast field antenna, denoted as +NBE, -CG, and -IC, respectively, in grey, orange, and light blue. The total of 49 lightning with the highest -CG followed by +NBE and +CG with the frequency of 32, 10 and 7 respectively. There are 2 drops occurred in the throughput client and server. The first one happens at the time of 13:32:03 to 13:32:04 for server and the other drop is 13:32:01 to 13:32:03 for client. Both of this reach 0 bit per second bandwidth. During the drop of the throughput occurred, there is a lightning recorded +CG and -CG where involved. Another lightning flashes were capture but the network was stable this time without no fluctuation to 0 bit of bandwidth.

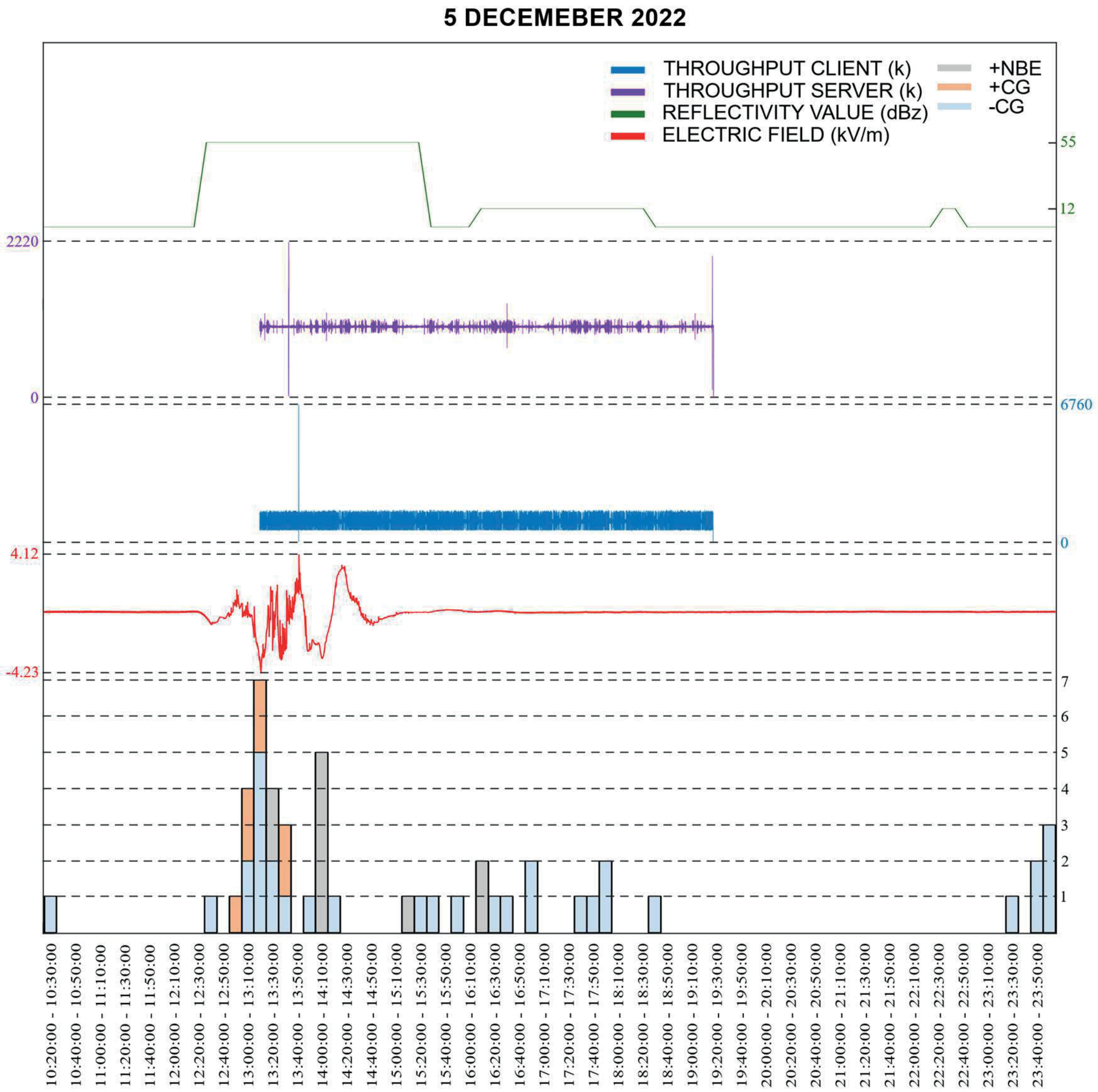

Figure 4: The plots of log files shows the data of througphut (Kbps) for client and sever in blue and purple respectively running for 13 hours and 40 minutes starting fro 10:20:00 to 00:00:00 on 5 December 2022. The green line plotting show the reflectivity value in dBz and the red color plot is the background electric field in kV/m.

4 Conclusion

The integration of the electric field measurement system with the automated weather station system not only reveals a robust correlation between lightning activity and rainfall during a specific period but also provides valuable insights into the temporal relationship between these phenomena. It becomes apparent that lightning occurs in close proximity, temporally speaking, right before the initiation of rainfall, underscoring the intricate dynamics between atmospheric electrical conditions and precipitation events.

5 Acknowledgment

This research work is supported by the Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS) with reference code FRGS/1/2022/TK07/UTEM/02/15. Also, we would like to thank Malaysian Technical Standards Forum Berhad (MTSFB) for industry grant with reference code INDUSTRI(IPDG)/MTSFB/2021/FKEKK/I00056. The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM), Malaysian Communications and Multimedia Commission (MCMC), Universiti Kebangsaan Malaysia (UKM), and U Mobile Sdn Bhd.

6 Reference

[1] D. Petersen and W. Beasley, ‘Microwave radio emissions of negative cloud-to-ground lightning flashes’, *Atmos Res*, vol. 135–136, pp. 314–321, Jan. 2014, doi: 10.1016/j.atmosres.2013.02.006.

[2] F. Shi, N. Liu, J. R. Dwyer, and K. M. A. Ihaddadene, ‘VHF and UHF Electromagnetic Radiation Produced by Streamers in Lightning’, *Geophys Res Lett*, vol. 46, no. 1, pp. 443–451, Jan. 2019, doi: 10.1029/2018GL080309.

[3] V. Cooray, ‘An Introduction to Lightning’, 2015.

[4] S.A.S. Baharin, M.R. Ahmad, A.A. Alkahtani, M.R.M. Esa, and M.A.B. Sidik, 'Temporal Analysis Of Microwave Radiation Emitted By Stepped Leaders of A Cloud-To-Ground Flash'. *Journal of Advanced Manufacturing Technology (JAMT)*, 14, no. 2 (2), 2020.

[5] S. A. S. Baharin *et al.*, ‘Microwave radiation associated with stepped leaders of negative cloud-to-ground flashes’, *Atmospheric Research*, vol. 270, Jun. 2022, doi: 10.1016/j.atmosres.2022.106091.

[6] M. R. M. Esa, A. Z. Sha’ameri, H. Ahmad, N. N. Nik, and A. Malik, ‘Conceptual Implementation to Access the Extend of Influence of Lightning Electromagnetic Radiation on Mobile Radio Communication’, In Asia-Pacific Conference on Applied Electromagnetics IEEE. pp. 5 pp, 2005, doi: 10.1109/APACE.2005.1607802.

[7] M. R. Ahmad, 'Interaction of Lightning Flashes with Wireless Communication Networks : Special Attention to Narrow Bipolar Pulses'. Acta Universitatis Upsaliensis, 2014.

[8] M. A. J. Akbar, M. R. Ahmad, S. A. S. Baharin, M. Abdullah, M. Z. A. A. Aziz, and G. Lu, ‘Large Scale Lightning Electromagnetic Interference to 4G Mobile Communication Network’, in *International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, Institute of Electrical and Electronics Engineers Inc., pp. 403–406. 2022. doi: 10.23919/EECSI56542.2022.9946479.

[9] S. A. S. Baharin, M. R. Ahmad, M. A. J. Akbar, and V. Cooray. 'Electromagnetic Interference from Natural Lightning on 4G Communication Links'. *IEEE Access,* 2024.

[10] N. Yusop *et al.*, ‘Cloud-to-Ground lightning observations over the Western Antarctic region’, *Polar Sci*, vol. 20, pp. 84–91, Jun. 2019, doi: 10.1016/j.polar.2019.05.002.