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Electromagnetic Interference from Natural Lightning on 4G Communication Links

SHAMSUL AMMAR SHAMSUL BAHARIN[1], MOHD RIDUAN AHMAD[1], (Member, IEEE), MUHAMMAD A'MMAR JAMAL AKBAR[2], AND VERNON COORAY[3], (Fellow, IEEE)

[1]Centre of Technology for Disaster Risk Reduction (CDR), Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Advance Micro Devices (AMDs), 11900 Bayan Lepas, Pulau Pinang, Malaysia
[3]Ångström Laboratory, Division for Electricity, Department of Engineering Sciences, Box 534, S-75121, Uppsala University, Sweden

Corresponding authors: Mohd Riduan Ahmad (riduan@utem.edu.my).

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ABSTRACT In this study, microwave radiation pulses emitted from natural lightning have been found to interfere with the Fourth Generation Long Term Evolution (4G LTE) mobile communication data transmission. Two sets of measurement instruments have been synchronized where lightning electric field sensor together with 4G LTE network were evaluated its performance under two conditions namely fair-weather (four cases) and storm (four lightning cases). The microwave radiation emitted from lightning was directly measured without the use of a mixer and down-convertor to ensure that information such as the number of pulses and amplitude was preserved. A client-server architecture has been set up for data transmission utilizing User Datagram Protocol (UDP) where the packets have been generated by using Internet Performance Working Group Third Version (Iperf3) platform. Under fair-weather conditions, the 4G LTE connection at both the client and server nodes demonstrated stability and experienced minimal impact. On the other hand, natural lightning electromagnetic interference disrupted the 4G LTE communication links. Among the four reported storms, three storms have affected the 4G LTE data transmission. The first and fourth storms resulted in a complete connection drop to zero, lasting for 4 minutes and 2 seconds and for 44 seconds, respectively. The observation of hundreds microwave radiation pulses, each characterized by individual oscillating features suggests a potential disruption to packet transmission. Moreover, negative could-to-ground (-CG) and intra-cloud (IC) lightning flashes have been identified as the primary sources of interference to the 4G LTE data transmission. This information could be useful for future studies and for developers working on improving the reliability and performance of 4G LTE networks, particularly in areas prone to thunderstorms.

INDEX TERMS Lightning interference, Microwave radiation, UDP, 4G mobile network

I. INTRODUCTION

Electromagnetic fields radiated from natural lightning flashes have been detected over a wide range of frequency spectrum. The topic of microwave radiation (0.3 to 300 GHz) emitted from natural lightning flashes garnered lots of interests for its relation to lightning initiation process. Generally, there are two main types of lightning flashes namely cloud-to-ground (CG) and intra-cloud (IC) flashes [1]. A special type of IC flash known as the narrow bipolar event (NBE) [2] was recently discovered to emit strong very-high frequency (VHF) and microwave radiation pulses. The first encounter of microwave radiation emitted from lightning flashes was observed in [3]. They reported microwave radiation associated with lightning activities at 0.4 and 0.85 GHz. Later, observations at 0.4, 0.7, and 0.9 GHz reported noise-like bursts of radiation that lasted around 10 ms [4]. Microwave radiation observation at 2.2 GHz reported significant bursts of impulsive activities during preliminary breakdown pulses (PBPs), stepped leaders, initial return strokes, dart leaders, and K changes

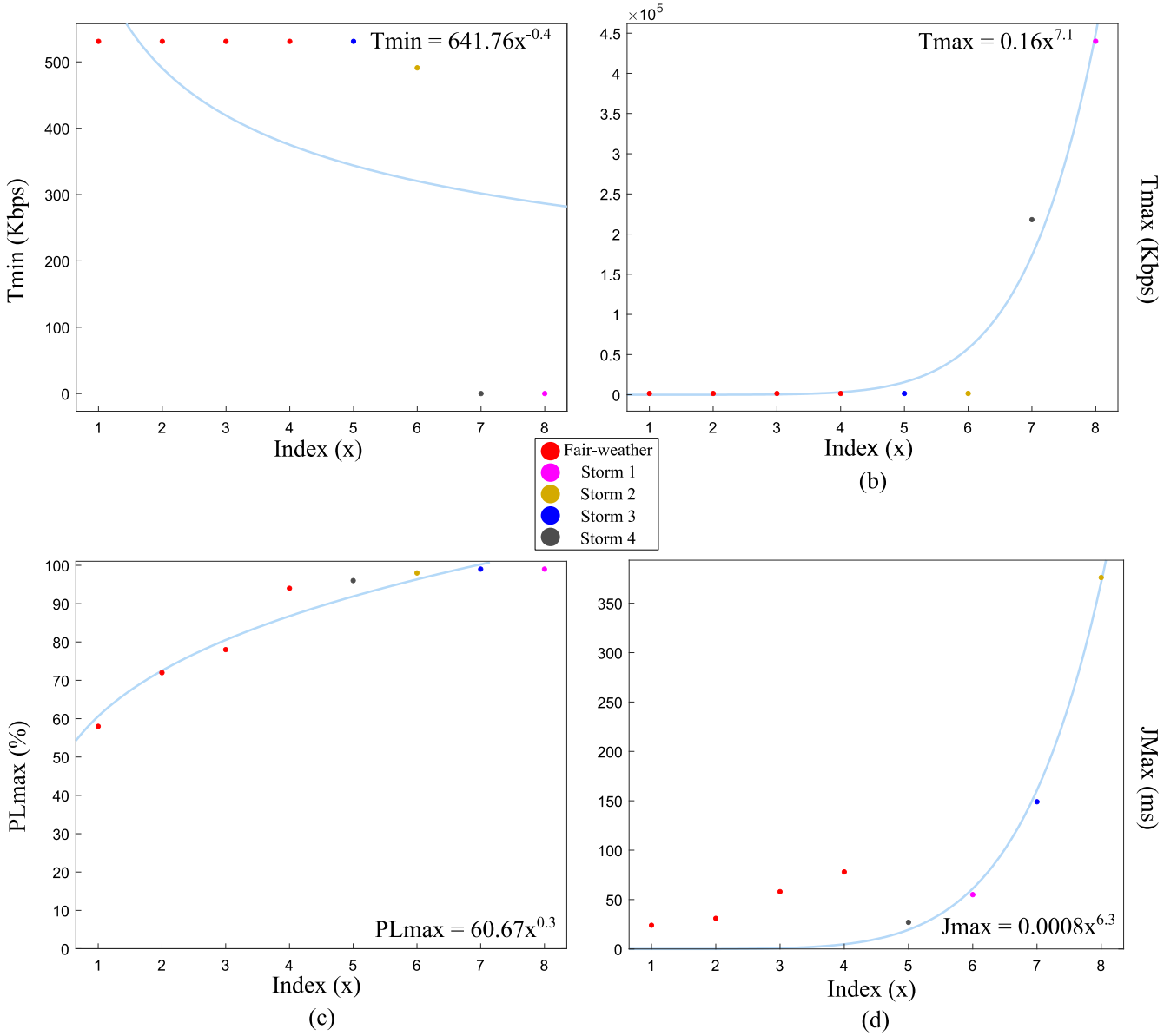

FIGURE 7. The relationship formulation of correlation analysis between fair-weathers (red dots) and storms and (a) minimum throughput at client node (Tmin/Kbps), (b) maximum throughput at client node (Tmax/Kbps), (c) maximum packet loss (PLmax/%) and (d) maximum jitter (Jmax/ms).

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REFERENCES

[1] V. Cooray, *An Introduction to Lightning*. Dordrecht: Springer Netherlands, 2015. doi: https://doi.org/10.1007/978-94-017-8938-7.

[2] D. M. Le Vine, "Sources of the strongest RF radiation from lightning," *Journal of Geophysical Research*, vol. 85, no. C7, pp. 4091–4095, Jul. 1980, doi: https://doi.org/10.1029/jc085ic07p04091

[3] M. Brook and N. Kitagawa, "Radiation from lightning discharges in the frequency range 400 to 1000 Mc/s," *Journal of Geophysical Research*, vol. 69, no. 12, pp. 2431–2434, Jun. 1964, doi: https://doi.org/10.1029/jz069i012p02431

[4] E.L. Kosarev, V. G. Zatsepin, and A. V. Mitrofanov, "Ultrahigh frequency radiation from lightnings," *Journal of Geophysical Research*, vol. 75, no. 36, pp. 7524–7530, Dec. 1970, doi: https://doi.org/10.1029/jc075i036p07524.

[5] Rust, W.D., Krehbiel, P.R., Shlanta, A., 1979. Measurements of radiation from lightning at 2200 MHz. Geophys. Res. Lett. 6 (2), 85–88.

[6] M.R. Ahmad, M.R.M. Esa, and V. Cooray, "Narrow Bipolar Pulses and Associated Microwave Radiation," in *Progress in Electromagnetics Research Symposium*, Stockholm, Sweeden, 2013, pp. 72–78.

[7] D. Petersen and W. Beasley, "Microwave radio emissions of negative cloud-to-ground lightning flashes," *Atmospheric Research*, vol. 135–136, pp. 314–321, Jan. 2014, doi: https://doi.org/10.1016/j.atmosres.2013.02.006.

[8] V. Cooray and G. Cooray, "Electromagnetic radiation field of an electron avalanche," *Atmospheric Research*, vol. 117, pp. 18–27, Nov. 2012, doi: https://doi.org/10.1016/j.atmosres.2011.06.004.

[9] A. Luque, "Radio Frequency Electromagnetic Radiation From Streamer Collisions," *Journal of Geophysical Research: Atmospheres*, vol. 122, no. 19, Oct. 2017, doi: https://doi.org/10.1002/2017jd027157

[10] F. Shi, N. Liu, J. R. Dwyer, and K. M. A. Ihaddadene, "VHF and UHF Electromagnetic Radiation Produced by Streamers in Lightning," *Geophysical Research Letters*, vol. 46, no. 1, pp. 443–451, Jan. 2019, doi: https://doi.org/10.1029/2018gl080309.

[11] S. A. S. Baharin *et al.*, "Microwave radiation associated with stepped leaders of negative cloud-to-ground flashes," *Atmospheric Research*, vol. 270, p. 106091, Jun. 2022, doi: https://doi.org/10.1016/j.atmosres.2022.106091.

[12] S. A. S. Baharin *et al.*, "Microwave radiation associated with positive narrow bipolar events," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 242, p. 105998, Jan. 2023, doi: https://doi.org/10.1016/j.jastp.2022.105998

[13] M. R. M. Esa, A. Z. Sha'ameri, H. Ahmad and N. N. N. A. Malik, "Conceptual implementation to access the extend of influence of lightning electromagnetic radiation on mobile radio communication," 2005 Asia-Pacific Conference on Applied Electromagnetics, Johor, Malaysia, 2005, pp. 5 pp.-, doi: 10.1109/APACE.2005.1607802.

[14] M. R. Ahmad et al., "Analysis of lightning-induced transient in 2.4 GHz wireless communication system," Proceeding of the 2011 IEEE International Conference on Space Science and Communication (IconSpace), Penang, Malaysia, 2011, pp. 225-230, doi: 10.1109/IConSpace.2011.6015888.

[15] M. R. Bin Ahmad, M. R. Mohd Esa, V. Cooray and E. Dutkiewicz, "Performance analysis of audio streaming over lightning-interfered MIMO channels," 2012 International Symposium on Communications and Information Technologies (ISCIT), Gold Coast, QLD, Australia, 2012, pp. 513-518, doi: 10.1109/ISCIT.2012.6380953.

[16] M. R. Ahmad, M. R. M. Esa, V. Cooray, and E. Dutkiewicz, "Interference from cloud-to-ground and cloud flashes in wireless communication system," *Electric Power Systems Research*, vol. 113, pp. 237–246, Aug. 2014, doi: https://doi.org/10.1016/j.epsr.2014.03.022.

[17] 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," 2022 9th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), Jakarta, Indonesia, 2022, pp. 403-406, doi: 10.23919/EECSI56542.2022.9946479.

[18] M. H. M. Sabri, M. R. Ahmad, A. A. Al-Kahtani, M. Z. A. A. Kadir, S. A. S. Baharin, G. Lu, H. Zhang, E. Williams, V. Cooray, F. H. Nordin, "A study of cloud-to-ground lightning flashes initiated by fast positive breakdown," Atmospheric Research, vol. 276, p. 106260, Oct. 2022, doi: https://doi.org/10.1016/j.atmosres.2022.106260.

[19] M. H. M. Sabri, A. A. Al-Kahtani, M. R. Ahmad, S. A. S. Baharin, G. Lu, Z. Kawasaki, V. Cooray, "Microwave Radiation Associated with Lightning Initiation Events of Negative Cloud-to-Ground Flashes," Atmosphere, vol. 13, no. 9, p. 1454, Sep. 2022, doi: https://doi.org/10.3390/atmos13091454.

SHAMSUL AMMAR SHAMSUL BAHARIN received the B.Sc. and M.Sc. degrees in Electronic Engineering from Universiti Teknikal Malaysia Melaka in 2018 and 2021, respectively. Currently, he is pursuing his Ph.D. degree at Universiti Teknikal Malaysia Melaka since November 2021. His Ph.D. research focuses on the characterization of microwave radiation emitted from lightning and the interference effects of lightning on mobile communication links. His research interests encompass antenna and microwave design and development, as well as the spatial and temporal characterization of lightning flashes in the microwave and VHF bands.

MOHD RIDUAN AHMAD earned his B.Sc. degree in Computer System and Communication Engineering from Universiti Putra Malaysia in 2003, followed by an M.Eng. degree with a specialization in the cross-layer design of MAC protocols for multi-in multi-out-based wireless sensor networks from the University of Wollongong, Australia in 2008. In 2014, he completed his Ph.D. with a specialization in atmospheric discharges at Uppsala University, Sweden. Currently, he holds the position of Associate Professor at the Faculty of Electronics and Computer Technology and Engineering at Universiti Teknikal Malaysia Melaka.

MUHAMMAD A'MMAR JAMAL AKBAR received the B.Sc in Electronic Engineering with Vice Chancellor award from Universiti Teknikal Malaysia Melaka in 2022. His Final Year Project was focusing on proofing of concept and correlation of interference of lightning toward 4G mobile communication link. His research interest was covering the topology of telecommunication system design and characterization of microwave radiation emitted by lightning flashes. Currently he is pursuing his career as a Product Development Engineer in Electrical Validation for Advance Micro Devices (AMDs).

VERNON COORAY a fellow of IEEE, obtained his Ph.D. from Uppsala University, Sweden, in 1982, specializing in electricity with a focus on electrical transients and discharges. In 2000, he became a Full Professor at Uppsala University, leading the Division for Electricity and Lightning Research. He has an extensive publication record, with over 400 scientific articles and 22 book chapters on topics related to lightning physics and electrical discharges. He has also edited three books. Dr. Cooray holds leadership roles in the scientific committees of prominent lightning research conferences and serves as the Editor-in-Chief of the Journal of Lightning Research.