

Prediction of Run-off Time for Water Film Thickness and the Effects on Wet Antenna Attenuation

^{*1}Amuda Y. Abdulrahman, ²Kazeem Salaudeen, ¹Sikiru O. Zakariyya,
¹Jimoh Akanni, ¹Akindele S. Afolabi and ³Aye T. Ajiboye

¹Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria

²Department of Biomedical Engineering, University of Ilorin, Ilorin, Nigeria

³Department of Computer Engineering, University of Ilorin, Ilorin, Nigeria

{abdulrahmanyusuf35|skazeemolawale}@gmail.com | {zakariyya.os|akanni|afolabisegun|ajiboye.at}@unilorin.edu.ng

Received: 06-JAN-2023; Reviewed: 06-MAR-2023; Accepted: 15-MAR-2023

<http://doi.org/10.46792/fuoyejet.v8i1.986>

ORIGINAL RESEARCH

Abstract- Most of the reported works on wet antenna attenuation (WAA) focused on the estimation of the water-layer thickness without considering the time taken to be drained off from the reflector (that is, the runoff time). Simulated rain experiments were conducted on a parabolic antenna with a diameter of 0.6 m. Based on measurement data, this study examined the parametric effects of rain rate on water film thickness and runoff duration, and then associated those findings to the overall WAA. It was found that WAA increases with the water film thickness, while decreasing with the runoff time. More so, the latter quantity both increase with the antenna dish size. The study is useful in accounting for the WAA component in the overall link budget design for adequate service delivery.

Keywords- Antenna reflectivity, Fade duration analysis, Link budget design, Rain rate, Runoff time, WAA, Water film thickness.

1 INTRODUCTION

When rain occurs along link pathways, Wet Antenna Attenuation (WAA) is seen as an extra factor diminishing the total received signal (Moroder *et al.*, 2020). WAA is mainly reliant on radio wave frequency, dimensions of the receiving antenna dish and the wetting conditions of antenna radome (Mandeep, 2009). Its effects become more severe at higher frequencies, higher elevation, longer link lengths and smaller antenna dish (Kharadly, 2001). WAA could also increase as a result of manufacturing processes that result in the reflector's surface being rough. (Crane & Rogers, 2002). The dielectric coating over the metal screen reflector may prevent water from running down the reflector. The combined impact of rain on the propagation channel and antenna is what causes rain attenuation to be directly measured. As reported in (Abdulrahman, 2012; Fencel *et al.*, 2019), The impacts of rain on antennas are represented as WAA and are caused by the interaction of two factors, specifically: (i) antenna losses owing to water film formation on the feed aperture surface and (ii) water pool build-up on the primary reflector.

In recent times, path attenuation and fading data in Commercial Microwave Links (CMLs), are used for determining the ground precipitation in weather observation. However, the accuracy of rain rates estimated from the measured signal levels depends on a deep understanding of the effect of wetness on antenna radome. WAA is also dependent on variation in antenna feed port reflectivity (Moroder *et al.*, 2020), which is a measure of the part of transmit power that is reflected back to the transmitter.

When the antenna reflectivity is degraded the receive signal level (RSL) is also reduced. Usually, the network operators only provide information about the transmitter output power, but that of antenna's feed port reflectivity is lacking, hence the actual power accepted at the receive antenna is not known. Reflectivity can be determined by near-field measurements in an anechoic chamber or by an electromagnetic simulator (Moroder *et al.*, 2020).

Several theoretical models of WAA could be found in the literature (Moroder *et al.*, 2020; Fencel *et al.*, 2019; Pastorek *et al.*, 2021; Islam *et al.*, 2002). In (Moroder *et al.*, 2020), the modelled WAA is separated into three components; that is, the antenna efficiency, directivity and antenna feed port reflectivity, otherwise characterized by antenna's receptivity. As reported in (Moroder *et al.*, 2020), both the antenna directivity and reflectivity increase with increasing water film thickness on the antenna surface. The efficiency of the antenna decreases as the water film thickness increases due to an increase in water film losses. The influence of reflectivity is low and when all the three parameters were combined, it was observed that WAA increases with increasing the thickness of the water film.

Also, an analytical approach for statistically estimating wet antenna losses from measured rain rate and attenuation was proposed in (Islam *et al.*, 2002), based on the wet antenna effects observed on some terrestrial microwave links propagating at 14.6, 21.95, 26, and 38 GHz in Malaysian tropical climates. The cumulative outcome of wet antenna losses on each of transmit and receive sides was factored into the proposed physical model. Moreover, at the University of Technology Malaysia (UTM) in Malaysia, experimental findings of wet antenna measurement on a 26 GHz terrestrial microwave link were published in (Rahim *et al.*, 2012). Again, the results of wet antenna measurement in vertically polarized signals propagating at 11.843 GHz on a slant path in Nigeria were reported in (Abdulrahman, 2022).

*Corresponding Author

Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES Can be cited as:

Abdulrahman A. Y., Salaudeen K., Zakariyya S. O., Akanni J., Afolabi A. S. and Ajiboye A. T. (2023). Prediction of run-off time for water film thickness and the effects on wet antenna attenuation, FUOYE Journal of Engineering and Technology (FUOYEJET), 8(1), 34-38. <http://doi.org/10.46792/fuoyejet.v8i1.986>

WAA causes additional losses to the overall signal fading along the propagation path during rain events, thereby adversely degrading the quality of service (QoS). Hence, in order to avoid tainting the actual propagation losses over the link, it has to be deducted from the total attenuation measured. The impact of rain rate on the thickness of water film, and runoff time are critically investigated in this work, using the measurement results reported in (Abdulrahman, 2022). Results that were attained are categorically highlighted at exceedance probability levels of 0.1, 0.01 and 0.001 %, being the most globally used by the telecommunications service providers (Mandeep, 2009). The impact of dish size on the thickness of water film and the runoff time is also studied. Therefore, the study can provide useful information on fade duration analysis owing to the WAA component in the overall link budget design and hence the required mitigation to sustain availability and reliable QoS.

2 THEORETICAL BACKGROUND

By assuming that the water layer thickness will be dispersed at random throughout the reflector, it is possible to estimate the attenuation brought on by water flowing on the antenna surface, or WAA. In a laminar flow, Gibble's expression provides the water thickness in Equation (1) (Abdulrahman, 2022):

$$t_w(R) = \sqrt[3]{\frac{3\mu_w r R}{2g}} \quad (1)$$

Where, $t_w(mm)$ is the water layer thickness, $\mu_w(m^2/s)$ represents the viscosity of water, $r(m)$ denotes the radius of reflective surface, $R(mm/h)$ is the rain rate, and $g(m/s^2)$ denotes the gravitational acceleration.

The runoff time, is derived by computing the gradient of with respect to rain rate, and it is derived as shown in Equations (2) – (4):

$$\frac{dt_w(R)}{dR} = \frac{1}{3} \sqrt[3]{\frac{3\mu_w}{2g}} r^{1/3} R^{-2/3} \quad (2)$$

$$\xi(R) = 0.4807 \left(\frac{\mu_w r}{2g} \right)^{1/3} R^{-2/3} \quad (3)$$

$$\text{where } \xi(R) = \frac{dt_w(R)}{dR} \quad (4)$$

3 EXPERIMENTAL SETUP AND DATA DESCRIPTION

The experiment was performed in Ilorin, the state capital of Kwara State, Nigeria; which is a sub-tropical climate with the propagation characteristics, as shown in Table 1 (Abdulrahman, 2022). A coaxial connection connects a parabolic antenna and a universal type low noise block (LNB) to a TBS-QBOX device, a digital satellite receiver, for the experimental setup. Using a USB cable, the TBS5980-QBOX was linked to a PC to act as the user interface. The geostationary satellite Eutelsat 36A at 36° E longitude with satellite beacon footprint at 11.843 GHz, and vertically polarized, was positioned in view of the receiving antenna, which has a diameter of 0.6 m, as indicated in Table 1.

In order to establish a baseline, the calibration of the receive signal level (RSL) was carried out by first testing the receiver in clear-sky weather circumstances, which are free of atmospheric absorptions such as rain and scintillation. When the sky is clear, the signal swings within $\pm 1V$, or around $\pm 5dB$, and is therefore rather steady. The accuracy of the data for wet antenna attenuation is close to 97% based on receiver calibration, while the greatest error that may be introduced by the conversion procedure is just approximately 3%. Every second, a sample and recording of the RSL's automatic gain control (AGC) level were made.

The polyvinyl chloride (PVC) bored pipes that make up the rainfall simulator are attached to a wood frame by a rubber tube and connected to a water supply. By altering the sprayer's nozzle, the water supply was managed such that its flow rate could be changed. The purpose is to simulate different rain intensities, which is the controlled variable, while the nozzle diameter is the controller parameter. A 20-cm-diameter tipping bucket setup with a 0.5-mm sensitivity was used to monitor the point rainfall rate during a 1-minute integration time. The tipping bucket rain gauge transmits data via wireless link to programmable data logger (TR525, manufactured by Texas Electronics, Inc), which records time of each tip to an accuracy of 0.1 s. To provide higher data resolution, the logger's clock was routinely synchronized with the computer's clock at intervals of 10 seconds.

A water measuring tube that can accurately measure 0.5 ml of water was used to calibrate the gauge in the lab. The simulated rain experiments conducted on the receiving antenna of an offset antenna reflector surface. There were four distinct sorts of experiments. Water drops with extremely low rainfall intensities, generally under 8 mm/h, were discharged during the initial test to establish equitable dispersion over the antenna reflecting surface. In the second test, a downpour of water droplets that were a few millimetres wide was allowed to flow at a pace of 10 to 45 mm/h. The third test sprayed the antenna with increased intensities of water, ranging from 50 mm/h to 110 mm/h, and in the fourth test, the highest intensities (more than 120 mm/h) were mimicked by splashing and allowing the water to fall across the antenna surface. The diagrammatic representation of the setup with the rainfall simulation arrangement is shown in Figure 1.

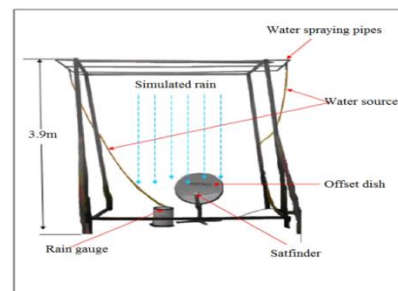


Fig. 1: Schematic of the rain simulator set-up

4 RESULT AND DISCUSSION

Analysis of the results obtained from the experimental set up is presented in subsections 4.1 to 4.3. The results obtained for $\xi(R)$ are highlighted at exceedance

probability levels of 0.1, 0.01 and 0.001 %, being the most common availabilities. The implications on fade duration analysis as result of WAA are also fully discussed. Lastly, the effect of dish size on $t_w(R)$ and $\xi(R)$ is parametrically studied, as presented in Subsection 4.2.

4.1 DATA ANALYSIS

According to (Abdulrahman, 2022), WAA exceeded at 0.01 % is about 2.98 dB when the water film thickness is 0.17 mm and radio frequency of 11.843 GHz. Using the ITU-R P. 618-17 extrapolation algorithm, the WAA values surpassed for various exceedance levels, p were determined (ITU-R. 2017). Figures 2 and 3, which are based on field measurements taken in Ilorin, a tropical climate in Nigeria, illustrate the rain rate and WAA cumulative distribution functions (CDFs) that were measured there. Figures 4 and 5, respectively depicts the graph of $t_w(R)$ and $\xi(R)$ against rain rate. Figure 6 depicts the relationship between $t_w(R)$ and $\xi(R)$ for the relative rain rates. WAA is related to both $t_w(R)$ and $\xi(R)$ as presented in Figures 7 and 8, respectively.

Figure 4 shows that $t_w(R)$ increases as the rate of rain increases, while Figure 5 shows that $\xi(R)$ decreases as the rain rate increases. As observed in Figure 6, an inverse relation exists between $t_w(R)$ and $\xi(R)$. The implication of the inverse relation is that, thicker water films run off faster down the reflector films due to gravity. In other words, the process of water accumulating and running off the surface happens more quickly the more rain falls.

WAA increases with $t_w(R)$, while decreasing with $\xi(R)$ as illustrated in Figures 7 and 8, respectively. The literature has also noted a correlation between an increase in $t_w(R)$ and a rise in WAA (Moroder et al., 2020; Kharadly, 2001; Islam et al., 2002). Consequently, the value of attenuation at any given instant is determined by the thickness of the water layer on the antenna surface. Depending on the size of the receiving antenna dish, WAA could also grow substantially at high radio wave frequency in addition to the wetting conditions of the antenna radome, as previously documented in (Mandeep, 2009; Kharadly, 2001).

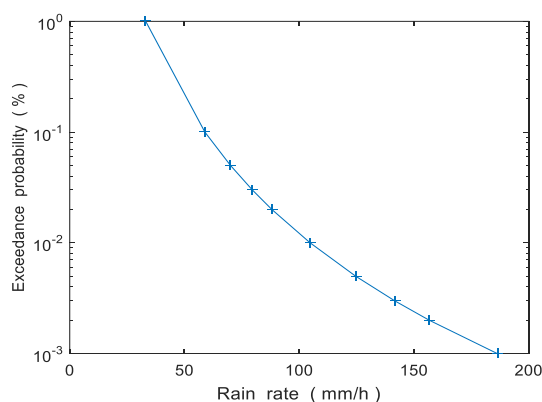


Fig. 2: Measured rain rate CDF

Table 1. Site's propagation characteristics

Frequency of the downlink signal	11.843 GHz
Polarization	Vertical
Antenna elevation angle	42°
Latitude	8.4912 °N
Longitude	4.5950 °E
Annual rainfall accumulation	1232.8 mm
Mean height above sea level	317 m
Average annual temperature	26 °C
Height of antenna	3.9m
Diameter of antenna	0.6m

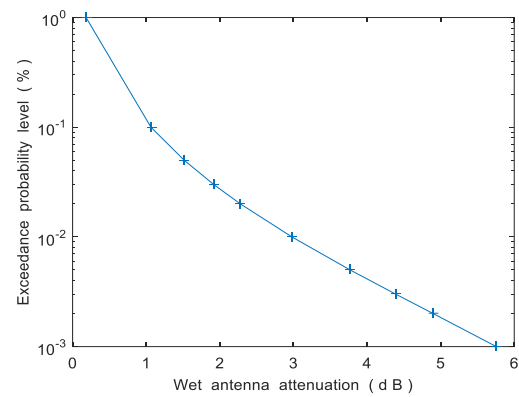


Fig. 3: Measured CDF of WAA

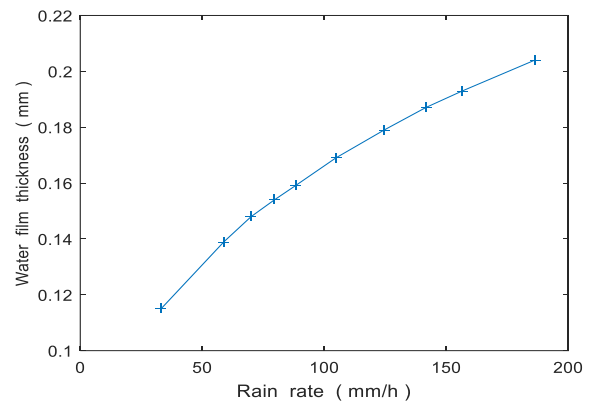


Fig. 4: Plots of $t_w(R)$ versus rain rate

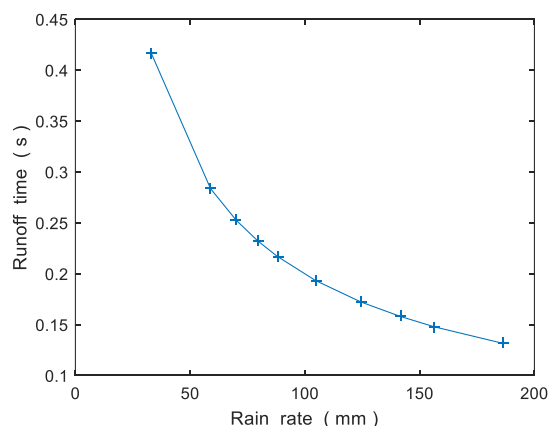
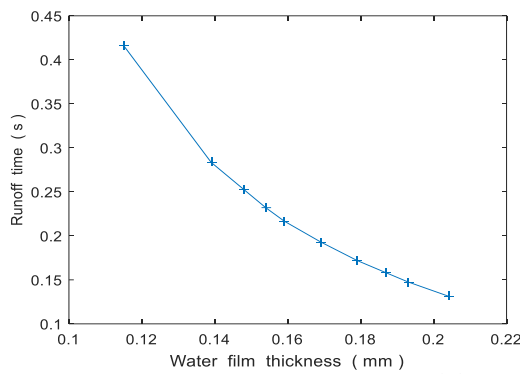
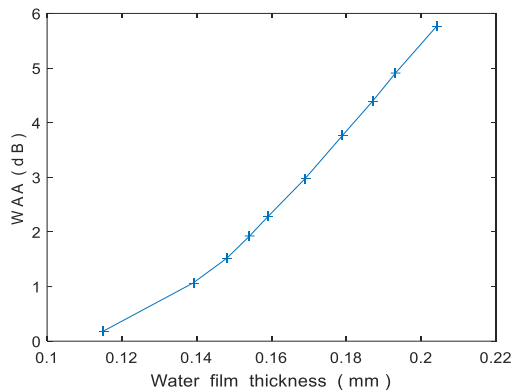
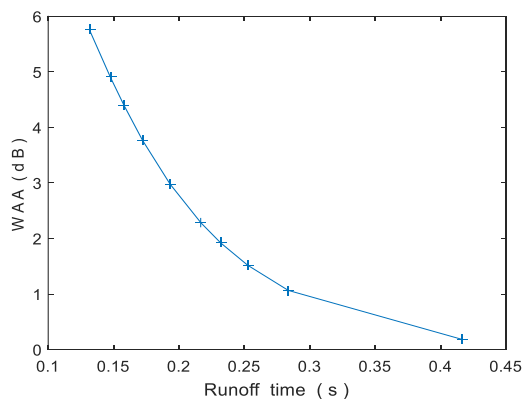
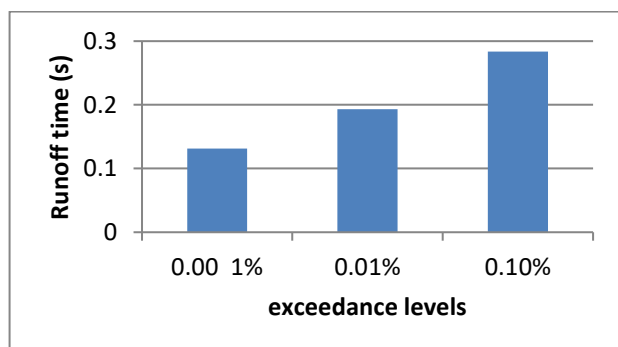


Fig. 5: Plots of $\xi(R)$ versus rain rate

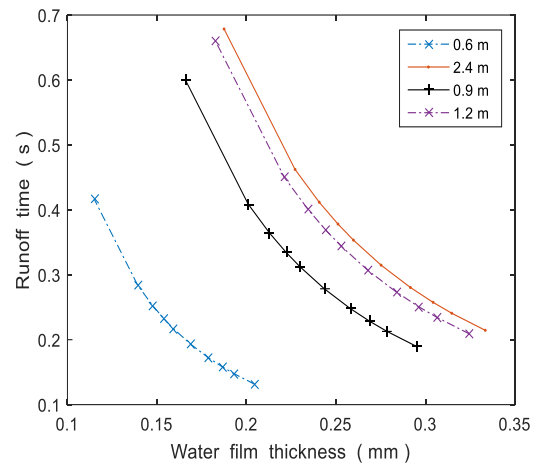

Fig. 6: Relation between $t_w(R)$ and $\xi(R)$

Fig. 7: Relation between WAA and $t_w(R)$

Fig. 8: Relation between WAA and $\xi(R)$

The outcomes attained for $\xi(R)$ are further highlighted at three exceedance levels, 0.1, 0.01 and 0.001 %, as illustrated in Figures 9, being the most globally used by the Telecommunications Service providers. The implication on fade duration analysis as a result of the WAA is also discussed, based on the achieved results.


Fig. 9: Values of $\xi(R)$ (in seconds), highlighted at 0.001%, 0.01% and 0.1 %.

4.2 INFLUENCE OF DISH SIZE ON WATER FILM THICKNESS AND RUNOFF TIME

The effect of dish size on $t_w(R)$ and $\xi(R)$ is parametrically studied, using diameters of 0.6, 0.9, 1.2 and 2.4 m, as presented in Figure 10.


Fig. 10: Influence of dish size on $t_w(R)$ and $\xi(R)$

4.3 DISCUSSION OF RESULTS

Figures 2 and 3 depict the rain rate and WAA CDFs, respectively, measured at Ilorin in Nigeria. The attenuation exceeded at 0.01 % is about 2.98 dB at water film thickness of 0.17 mm and radio frequency of 11.843 GHz. According to Figures 4 and 5, increasing the rain rate increases the water film thickness while decreasing the runoff time $\xi(R)$, which causes the collected water film to run off more quickly due to gravity. As observed in Figure 6, the inverse relation between $t_w(R)$ and $\xi(R)$ demonstrates that the thickness of water-layer is significantly influenced by the accumulation and discharge of water on the surface.

WAA increases with $t_w(R)$ while decreasing with $\xi(R)$, as presented in Figures 7 and 8, respectively. Since WAA decreases with runoff time, it means thick water film layers, due to high rain rates, will run off faster and hence resulting only in short-term fading. Outcomes of $\xi(R)$ shown in Figures 9 are interpreted as follows. For instance, at unavailability levels of 0.001% (186.225 mm/h), 0.01% (104.722 mm/h) and 0.1% (58.8895 mm/h), the $\xi(R)$ values are 0.1315, 0.1931 and 0.2835 s, respectively. These results imply that the runoff time decreases with increasing rain rate, thereby resulting only in short-term fading; and vice versa. The results further conform to the fact that, propagation impairments often only have a substantial impact for less than or equal to one percent of the time within a year ($p \leq 1\%$), as earlier cited (Moroder et al., 2020).

The impact of dish size on each of $t_w(R)$ and $\xi(R)$ is parametrically studied by varying the dish diameter, using 0.6, 0.9, 1.2 and 2.4 m, as depicted in Figure 10. The results showed that, given the same amount of rain rate, both $t_w(R)$ and $\xi(R)$ increase with dish size. For example, at an extremely high rain rate of around 186.225 mm/h (0.001%), the values of $t_w(R)$ are 0.2045, 0.258, 0.295 and 0.325 mm for the 0.6, 0.9, 1.2 and 2.4 m dishes,

respectively. The equivalent values of $\xi(R)$ are 0.1315, 0.1657, 0.1897, 0.2088 s. More so, at an extremely low rain rate of about 33.116 mm/h (1%), the values of $t_w(R)$ are 0.115, 0.1658, 0.1825 and 0.1875 mm for the 0.6, 0.9, 1.2 and 2.4 m dishes, respectively. The corresponding values of $\xi(R)$ are 0.4162, 0.6002, 0.6606 and 0.6785 s. According to the findings, the dish size can also have an impact on WAA. Essentially, accumulation and runoff occur more quickly for a larger dish, implying a lower value of $\xi(R)$, hence shorter fade duration and less severe wet antenna effects. The converse is the case for a smaller dish.

The type of antenna (e.g., shape, cover material), the wind direction, nearby obstructions, etc., all affect how much rain falls and how thick the resulting water layer is. The fact that there is more rain falling on the antenna during more heavy rainstorms should be observed; however, this does not necessarily mean that there is more water being held on the antenna surface. So, it can be summarized that, the runoff time increases with dish size. That is, for smaller antenna dish, the runoff time is very high thereby resulting in long-term fading. Due to the findings of this investigation, the argument in (Kharadly, 2001) that the effects of WAA become more severe with smaller antenna dishes is further supported.

5 CONCLUSION

The amount of water that is present on the antenna surface at any one time determines the attenuation value at that time. While the runoff duration lowers with rain rates, the water layer thickness grows. The building and runoff of water on the surface have a big impact on the water layer's thickness; in other words, the faster the build-up and runoff processes, the more the rain rate. The relationship between the runoff time and water film thickness was found to be inverse. More so, WAA increases with water layer thickness, while decreasing with runoff time, for a given amount of rain rate. The WAA decreasing with runoff time implies that, thick water film layers, brought on by significant rain rates, will run off faster and hence resulting only in short-term fading.

Furthermore, the results achieved for runoff time are further highlighted at three exceedance levels, 0.1, 0.01 and 0.001 %, being the most globally used availabilities by the service providers. Also, the implication of these results on fade duration analysis as a result of the WAA was discussed. When rain rate is very high the runoff time is very small thereby resulting only in short-term fading. Conversely, when rain rate is very low the runoff time is very high thereby resulting in long-term fading. The findings of this study have further supported the idea that propagation limitations often only have an impact for a brief period of time, typically $p \leq 1.0\%$.

Finally, the effect of dish size on water layer thickness and runoff time was also parametrically studied. The results showed that, with a specific rain rate, both water layer thickness and runoff time increase with dish size, which eventually affect the WAA. For a larger dish, the build-up and runoff process are faster, implying a lower value of

runoff time, hence shorter fade duration and less severe wet antenna effects. The converse is the case for a smaller dish.

REFERENCES

- Abdulrahman, A. Y. (2012). Development of terrestrial rain attenuation transformation model for slant-path attenuation predictions in tropical region. *Doctoral Thesis in Electrical Engineering at the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, UTM, Malaysia*.
- Abdulrahman, A. Y. (2022). Analysis of wet antenna losses on 11.843 GHz slant path in Nigeria and comparison with some tropical climates. *Journal of Microwaves, Optoelectronics and Electromagnetic Application*, 21 (2), 207–219.
- Crane, R. K., & Rogers, D. V. (2002). Comments on Effects of Wet Antenna Attenuation on Propagation Data Statistics. *IEEE Transactions on Antennas and Propagation*, 50 (9), 1331–1332.
- Fencl, M., Valtr, P., Kvicera, M., & Bares, V. (2019). Quantifying wet antenna attenuation in 38 GHz commercial microwave links of cellular backhaul. *IEEE Geoscience and Remote Sensing Letters*, 16 (4), 514 – 518.
- Islam, M. R., Tharek, A. R., Din, J., & Chebil, J. (2002). Measurement of Wet Antenna Effects on Microwave Propagation – Analytical Approach. *Asian-Pacific Microwave Conference, Sydney, NSW, Australia*, 1547-1551.
- ITU-R. (2017). Propagation data and prediction methods required for the design of Earth-space telecommunication systems. *International Telecommunication Union (ITU-R) Recommendation. Geneva (Switzerland)*. 618-10.
- Kharadly, M. M. Z. (2001). Effect of Wet Antenna Attenuation on Propagation Data Statistics. *IEEE Transactions on Antennas and Propagation*, 49 (8), 1183 – 1191
- Mandeep, J. S. (2009). Analysis Effect of Water on a Ka-band Antenna. *Progress In Electromagnetics Research Letters*, 9, 49-57.
- Moroder, C., Siart, U., Chwala, C., & Kunstmann, H. (2020). Modeling of wet antenna attenuation for precipitation estimation from microwave links. *IEEE Geoscience and Remote Sensing Letters*, 17 (3), 386 – 390.
- Pastorek, J., Fencl, M., Riechelmann, J., & Bares, V. (2021). Precipitation Estimates from Microwave Links for Urban Hydrology: Improving the Accuracy Using Wet-Antenna Calibration. *8th International IEEE Conference on Microwaves, Communications, Antennas, Biomedical Engineering and Electronic Systems – CELLular ENvironment MONitoring (CELLENMON) Special Session*, 2021.
- Rahim, S. K. A., Abdulrahman, A. Y., Rahman, T. A., & UI-Islam, M. R. (2012). Measurement of Wet Antenna Losses on 26 GHz Terrestrial Microwave Link in Malaysia. *Wireless Personal Communications*, 64, 225 – 231.
- Rios Gaona, M. F., Overeem, A., Raupach, T. H., Leijnse, H., & Uijlenhoet, R. (2018). Rainfall retrieval with commercial microwave links in São Paulo, Brazil. *Atmospheric Measurement Techniques*, 11 (7), 4465–4476.