Localized Rain Effects Observed in Tokyo Tech Millimeter-wave Model Network

Hung Vu Le #1, Takuichi Hirano #, Jiro Hirokawa #, Makoto Ando #

Graduate School of Engineering, Tokyo Institute of Technology
Ookayama, 2-12-1-S3-19 Meguro-ku, Tokyo, 152-8552, Japan
1 `vuhung@antenna.ee.titech.ac.jp`

***Abstract*—In this paper, we have analyzed the effects of rain on millimeter-wave propagation. The purpose of this research is to evaluate the localized behaviors of rain and its effects on millimeter-wave propagation. Tokyo Tech millimeter-wave model network was employed to measure signals and rainfall in the university campus. The statistical analysis results show that the localized behaviors of rain affects the rain attenuation at both rain rates and path distance.**

I. INTRODUCTION

Millimeter-wave technology has been known for many decades, the systems using this technology have mainly been deployed for military applications. However, recently, millimeter-wave technology has attacted a great deal of interest from academia, industry and global standardization body. Even though this technology has been proven advantages in terms of high speed, large-capacity information transmission, it is also obsevable that the millimeter-wave has not been promoted as expected. One of the biggest challenges for designing a millimeter-wave system is the limited link budget due to rain fade during radio wave propagation. In many studies in the field of millimeter-wave propagation, there have been a number of paper investigated the attenuation due to rain [1], [2]. All the researches, as mentioned above, are focused mainly on rain attenuation characteristics with the long propagation path. An important aspect in the understanding of rain attenuation characteristics in small areas is localized behaviors of rain. Of special note is the correlation coefficient, which is an essential parameter for diversity. Currently, there a few studies on the analysis of localized behaviors of rain and its effects on radio wave propagation. In previous reports [3], the results show that the localized behaviors of rain affects the rain attenuation at high rain rates especally for long path. Also spatial correlation of rain rates has been investigated. However, the results of this study have generally not provided clear evidence of a relationship between spatial correlation and specific rain attenuation. Further investigation is essential to better understand a relationship between spatial correlation and specific rain attenuation.

The aim of this research is to evaluate the localized behaviors of rain and its effects on millimeter-wave propagation. Millimeter wave model network was developed in Ookayama campus, Tokyo Institute of Technology (Tokyo Tech) in 2008, this model network in order to investigate propagation characteristics for outdoor applications, such as 25GHz and 38GHz band fixed wireless access (FWA) systems. Various works have been conducted on rain attenuation characteristics in the sub-millimeter/millimeter wave band [1], [2]. Another application of this system as rain tracker, which can be used to estimate the rain rate [4].

The rest of the paper is organized as follows. The system is described in detail in Section 2. Section 3 shows the localized behaviors of rain. Finally, the conclusion is drawn in Section 4.

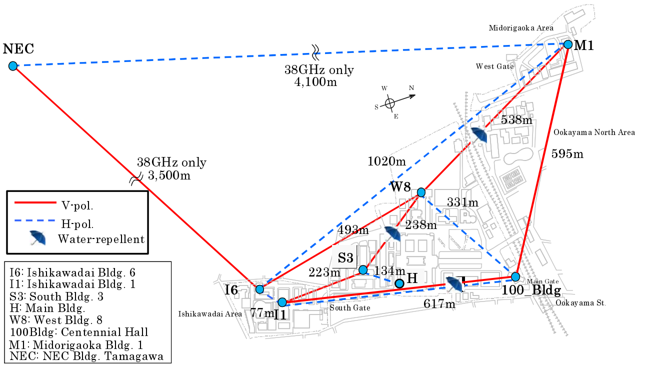
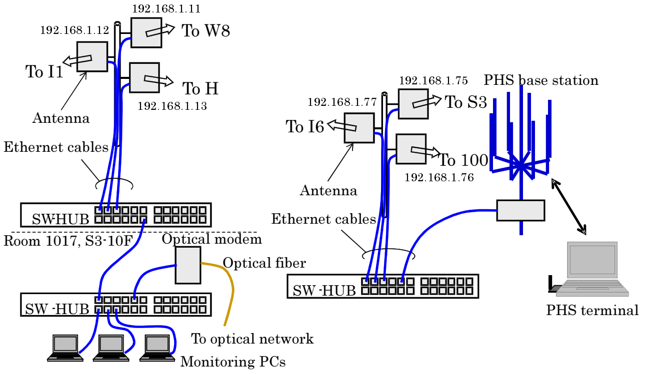


Fig. 1: Tokyo Tech millimeter-wave model network



(a) South Bldg. 3 (b) Ishikawadai Bldg. 1

Fig. 2: Schematic for the propagation experiment

II. TOKYO TECH MILLIMETER-WAVE MODEL NETWORK

Tokyo Tech millimeter-wave model network consists of 13 FWA links, 8 base stations and 3 PHS base stations [3], [4]. The FWA lines are connected with each other using network

(a) 25GHz Terminal

(b) 38GHz Terminal

Fig. 3: Wireless terminals

TABLE I: Wireless Terminal Specification

RF	**25GHz**	**38GHz**
Bandwidth	20MHz	200MHz
Duplex scheme	TDD	TDD
Modulation Scheme	16QAM	QPSK/16QAM
Antenna Gain	29dBi	32dBi
Max Transmission Speed	80Mbps	600Mbps

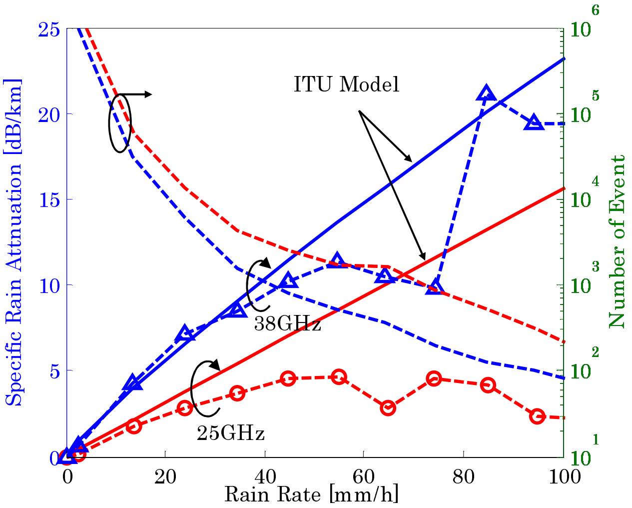


Fig. 4: Specific Rain Attenuation vs. Rain Rate

switches at 8 FWA base stations on the rooftops of 8 buildings, as shown in Fig. 1. The shortest path is 77m and the longest one is 1020m.

Furthermore, two extra paths (3500m and 4100m) have been set up outside of the campus for accurate evaluation of the link availability of the 38GHz network. Figs. 2 and 3 show photographs of wireless terminals and monitoring equipment respectively. High gain antennas are used for the FWA terminals which have specifications listed in Table 1. Rx level is measured using received signal strength indication (RSSI) information. BER, or the numbers of bit errors, can be calculated by the result of Reed-Solomon error correction. Rx level and BER are stored in the FWA terminal, and they are collected by monitoring PCs using simple network management protocol (SNMP) via Ethernet of the model network. Rain rate, received signal level (Rx Level), bit error rate (BER) are recorded every 5 seconds. Rainfall intensity is measured by tipping-bucket rain gauges with 0.2mm resolution installed at all base stations.

III. LOCALIZED BEHAVIOR OF RAIN

To clarify the mechanism of the localized behaviors of rain, a statistical analysis of long-term observations of rain rate is necessary. In this research, 2 year 3 months' data (March 2010 - May 2012) have been used.

A. Evaluation of Rain Rate Dispersion

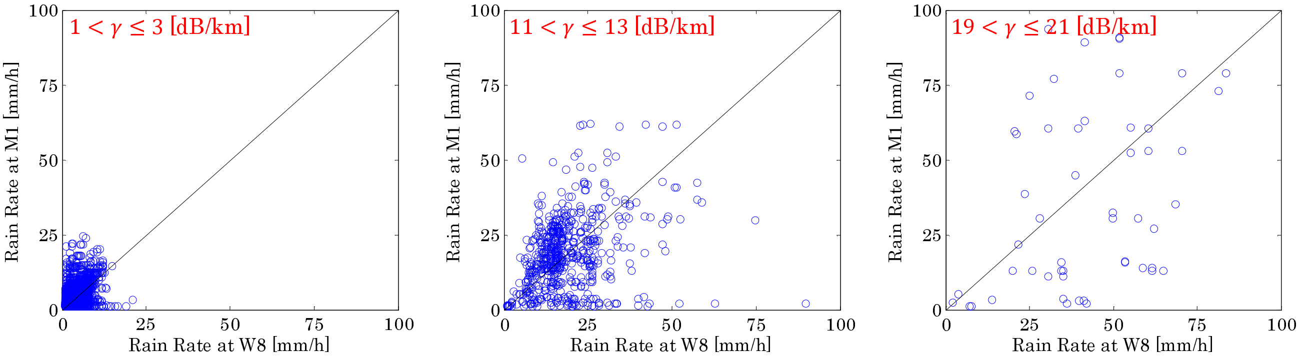
In the millimeter-wave band, the attenuation due to rain increases as the frequency goes up. This is also verified as shown in Fig. 4. It can be observed that the attenuation for 38GHz link is larger than that of 25GHz link. The experimental data approximately follows the ITU curve [8] in case of rain rate below 40mm/h, while it depart from ITU curve in case of rain rate above 40mm/h. This means the rain rate is not uniformly distributed along the propagation path, or put differently, the longer the path is the more dispersion the rainfall is. The number of events is also shown in this figure. The number of observed rain rate is small, so the long-term observation of measured rain rate is required to describe this result.

Fig. 5 shows the dispersion of rain rate between two points of path at different ranges of specific rain attenuation. The 45-deg line is also drawn in these figures. It is clear that the stronger dispersion of rain rate, the larger specific rain attenuation. The figure also shows the dispersion of rain rate is dependent on the distance of propagation path. The relatively high values of dispersion from 45-deg line indicate that the rain rate is highly varying in distance.

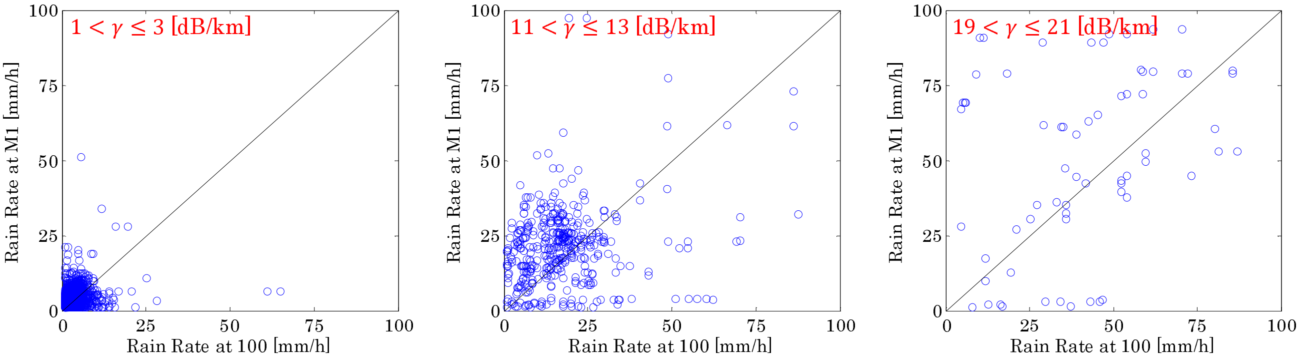
Next, the relationship between the specific rain attenuation and rain intensity will be investigated. The variation of rain rate is observed in the range of specific rain attenuation $\gamma = \{x|a < x \leq b, (a,b) = \{(1,3),(3,5),(5,7),\cdots,(17,19),(19,21)\}\}$ with the unit is [dB/km]. Fig. 6 shows the distribution of average rain rate of path at three ranges 1,6 and 10. The spread of a distribution refers to the variability of the rain rate. There is a clear relation found between specific rain attenuation and rain rate. The rain attenuation is large, the spread is larger. The mean values are also plotted in the same figure. The mean values of rain rate are 2.0, 12.1 and 36.1[mm/h], respectively. From Fig. 4, it is observed that these values are slightly lower compared to the ITU cover. There are some reasons to explain for this result. For example, radomes protect the antenna surfaces from the environment that leads to the experimental results do not match with the ITU cover. Table 2 summarizes the statistics of average rain rate. It shows that the variation of rain rate becomes clear when specific rain attenuation changes.

B. Spatial Correlation of Rain Rate

In [5], authors present 13 different formulas of correlation coefficient, each of which represents a different computational and conceptual definition of correlation coefficient. To calculate the spatial correlation, the Pearson correlation, which as a function of raw scores and means, is the usual formula found in introductory statistics textbooks. The mathematical formula



(a) Path Distance: 538m



(b) Path Distance: 595m

Fig. 5: Dispersion of rain rate from 45-deg line

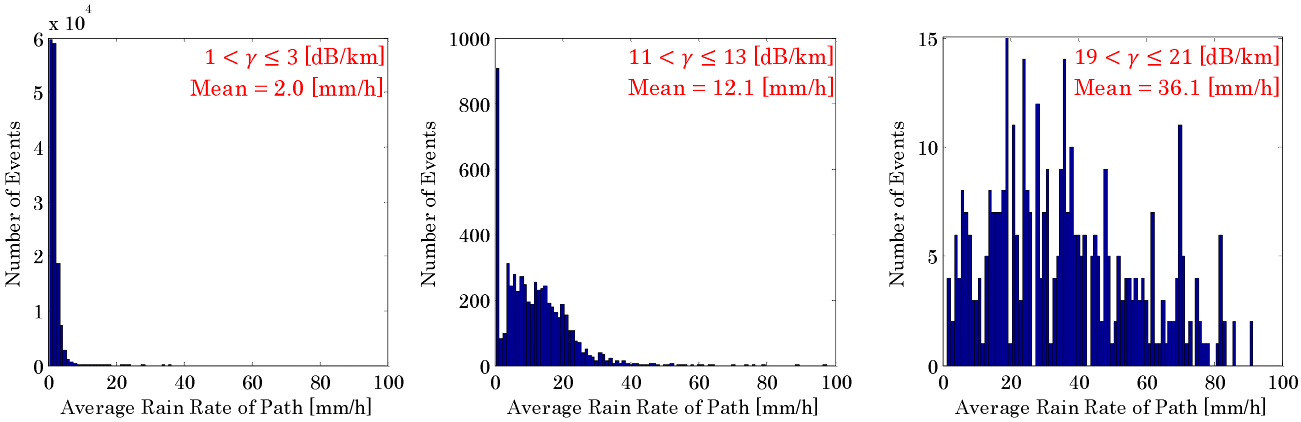


Fig. 6: Distribution of average rain rate

is given by

$$\rho = \frac{\sum_{i=1}^{N}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}}, \tag{1}$$

where X, Y are two random rain rate variables, $\bar{X}, \bar{Y}$ are mean values of data set.

The correlation may also be expressed as a function of the angle between the two variable vectors. This definition is a measure of similarity between two vectors of an inner product space, and it is given by

$$\rho' = \rho_{\begin{pmatrix}\bar{X} \to 0 \\ \bar{Y} \to 0\end{pmatrix}} = \cos(\theta), \tag{2}$$

where θ is an angle between two vectors.

In [6], [7], the authors explained the difference between cosine measure and Pearson's correlation coefficient in geometrical terms. The Pearson correlation normalizes the values of the vectors to their arithmetic mean. In geometrical terms,

TABLE II: Summary of average rain rate statistics

Range	γ [dB/km]	Mean [mm/h]	Standard deviation [mm/h]
1	$1 < \gamma \leq 3$	2.0	1.2
2	$3 < \gamma \leq 5$	2.7	1.8
3	$5 < \gamma \leq 7$	4.5	3.1
4	$7 < \gamma \leq 9$	6.8	4.6
5	$9 < \gamma \leq 11$	9.4	7.0
6	$11 < \gamma \leq 13$	12.1	9.7
7	$13 < \gamma \leq 15$	17.9	12.0
8	$15 < \gamma \leq 17$	19.5	14.1
9	$17 < \gamma \leq 19$	26.5	18.0
10	$19 < \gamma \leq 21$	36.1	21.2

this means that the origin of the vector space is located in the middle of the data set, while the cosine constructs the vector space from an origin where all vectors have a value of zero. Visually, this definition is much easier to view the correlation by observing an angle than by looking at how points cluster about the regression because it directly observe the size of an angle between two vectors.

Fig. 7 shows the correlation coefficient, which is calculated by using the Pearson's correlation coefficient and cosine similarity measure. Each correlation coefficient data is obtained by using rain rate at any two points with different ranges of specific rain attenuation. The color of markers represents correlation level. It can be confirmed that in both cases, the spatial correlation of rain rate decreases with the increase in path distance and specific rain attenuation. In Fig. 7(a), the spatial correlation of rain rate is calculated by using the Pearson's correlation coefficient, the graph does not become smooth. However, in the second graph, the correlation looks rather smooth as the dispersion of rain rate is a measure of similarity between two vectors of an inner product space. Therefore, the cosine measure should be selected to measure the dispersion of rain rate.

From the above evaluations, the effects due to localized behaviors of rain have become clear. It shows that the spatial correlation is a good parameter for diversity.

IV. CONCLUSION

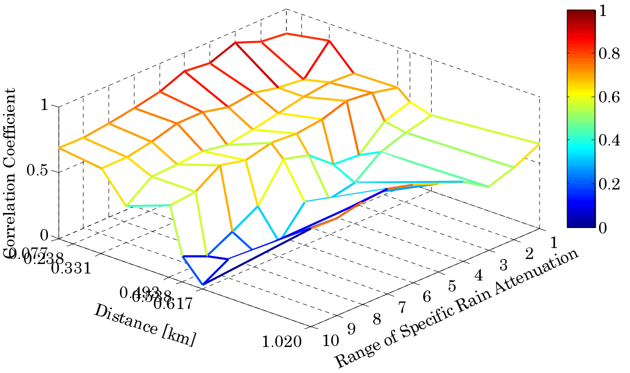
In this paper, the effects of rain on the millimeter-wave propagation are analyzed. The dispersion and spatial correlation of rain rate are evaluated. The statistical analysis results show that the rain attenuation is affected by the localized behaviors of rain affects at both high rain rates and long path. It also shows that the spatial correlation is a good parameter for diversity.

ACKNOWLEDGMENT

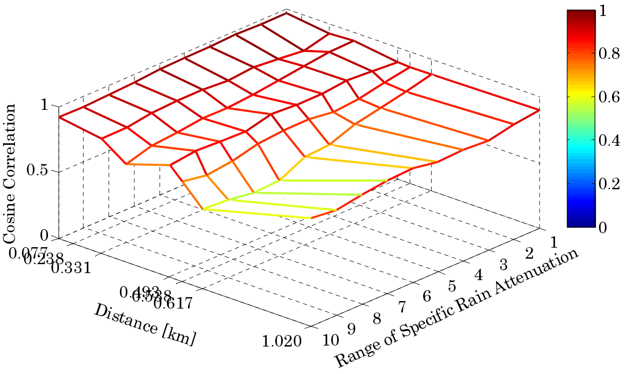
This work was conducted in part as "the Research and Development for Expansion of Radio Wave Resources" under the contract of the Ministry of Internal Affairs and Communications.

REFERENCES

[1] O. Sasaki, I. Nagamune, K. Sato, Y. Hosoya, "Rain attenuation characteristics on 20 GHz band multirelay links," Antennas and Propagation, IEEE Transactions on , vol.29, no.4, pp. 587- 594, Jul. 1981.



(a) Pearson's Correlation Coefficient



(b) Cosine Correlation

Fig. 7: Correlation Coefficient

[2] T. Manabe and T. Yoshida, "A study on rain attenuation characteristics of quasi millimeter waves," Journal of IEICE Vol. J78-B-II no.1, pp. 11-20, Jan. 1995.

[3] M. Ando, M.M. Hasan, R. Jayawardene, T. Hirano, J. Hirokawa, "Localized behaviors of rain measured in Tokyo Tech millimeter-wave wireless network," in Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP 2011), Apr. 2011, pp.1688-1692.

[4] T. Hirano, J. Hirokawa, M. Ando, "Estimation of rain rate using measured rain attenuation in the Tokyo tech millimeter-wave model network," IEEE Antennas and Propagation Society International Symposium (APSURSI 2010), Jul. 2010, pp.1-4.

[5] J. L. Rodgers and W. A. Nicewander, "Thirteen ways to look at the correlation coefficient," The American Statistician, vol. 42, pp. 59-66, 1988.

[6] L. Egghe and L. Leydesdorff, "The relation between Pearson's correlation coefficient r and Salton's cosine measure," J. Am. Soc. Inf. Sci., vol.60, pp. 1027-1036, May 2009.

[7] W. P. Jones and G. W. Furnas, "Pictures of relevance: A geometric analysis of similarity measures," Journal of the American Society for Information Science, vol.38 no. 6, pp. 420-442, Nov. 1987.

[8] Rec. ITU-R P.838-3, "Specific attenuation model for rain for use in prediction methods," ITU-R Recommendations and Reports, ITU, Mar. 2005.