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Millimeter-Wave Rain Sensing Networks using Dual-Frequency Measurements

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***Abstract*—In this paper, we propose a novel method for rain sensing using dual-frequency measurements at 25 and 38 GHz from small-scale Tokyo Tech millimeter-wave network. A real-time algorithm was developed for estimating the rain rate using ITU-R relationships and new coefficients to consider the effects of the rain Drop Size Distribution (DSD). The results show that the proposed algorithm provides the estimation in very good agreement with rain gauge data.**

***Index Terms*—millimeter wave network, rain attenuation, rain sensing, dual-frequency.**

I. INTRODUCTION

In the past few years, the increasing demand for broadband communications has required the use of higher frequencies. Millimeter-waves have received substantial attention because of their high-speed data transmission capabilities and creation of new frequency resources [1]. In practice, one of the disadvantages of millimeter-wave systems is that these signals can be disrupted by rain. However, millimeter-waves can be used for local weather monitoring, tracking the localized rainfall in real-time. It is an important method in reducing damage due to the heavy rainfall. In this paper, we propose a novel method for rain sensing using dual-frequency measurements at 25 and 38 GHz from small-scale Tokyo Institute of Technology (Tokyo Tech) millimeter-wave network. A real-time algorithm was developed for estimating the rain rate using ITU-R relationships and new coefficients to consider the effects of the Drop Size Distribution (DSD). The suggested procedure is tested on measured data, and its performance is evaluated.

II. MEASUREMENT SYSTEM

The Tokyo Tech millimeter-wave model network consists of 18 Fixed Wireless Access (FWA) links (9 links for 25 GHz and 9 links for 38 GHz, respectively) as depicted in Fig. 1. The FWA links are connected to each other using network switches at the 6 FWA base stations. The shortest link is 77 m and the longest is 1020 m. Some basic research into millimeter-wave propagation characteristics using this network has been reported in [2]. The Rx level and Bit Error Rate (BER) are tentatively stored in the FWA terminal and are monitored by PCs. Rainfall intensity is measured by tipping-bucket rain gauges installed at all base stations with 0.2 mm resolution as the average of 1-minute time intervals. The rain rate, Rx Level, and BER are recorded every 5 seconds from 2009 onwards. In this research, several rainfall events are selected for the analysis to evaluate the proposed technique.

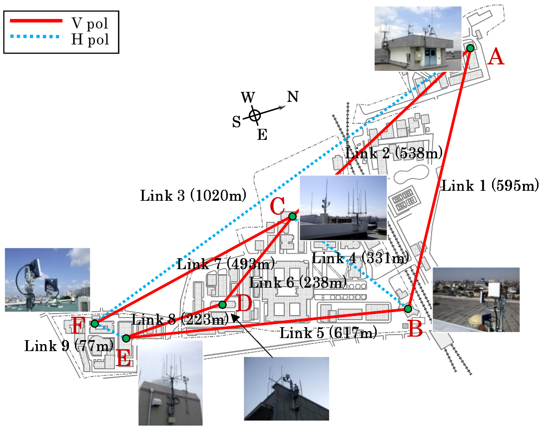

Fig. 1: Tokyo Tech millimeter-wave model network.

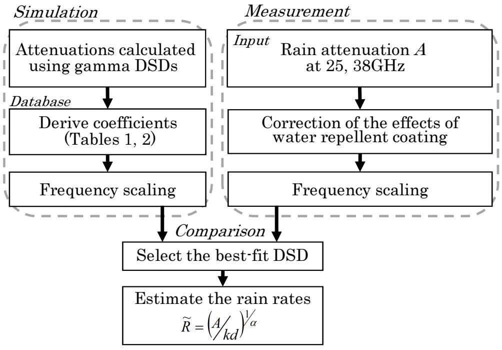

Fig. 2: A real-time algorithm for estimating rain rate.

III. RAIN SENSING

Fig. 2 shows a flowchart of the proposed real-time algorithm for estimating rain rate R using the measured rain attenuation A. The frequency scaling technique is used to find the optimal coefficients k and α for estimating rain rate. These coefficients are obtained by a linear best-fit procedure on log-log axes in the $R - \gamma$ plane for each of the DSDs considered [3]. The

TABLE I: The k, α coefficients at $f = 25$ GHz

DSD	k_H	α_H	k_V	α_V
Marshall-Palmer	0.1066	1.0865	0.1010	1.0537
Gamma, $\mu = -3$	0.1273	1.0172	0.1160	0.9735
Gamma, $\mu = -2$	0.1209	1.0428	0.1119	0.9983
Gamma, $\mu = -1$	0.1153	1.0657	0.1079	1.0259
Gamma, $\mu = 0$	0.1108	1.0801	0.1043	1.0461
Gamma, $\mu = 1$	0.1076	1.0852	0.1017	1.0568
Gamma, $\mu = 2$	0.1055	1.0844	0.0998	1.0610
Gamma, $\mu = 3$	0.1051	1.0797	0.0989	1.0613
ITU-R 838-3	0.1571	0.9991	0.1540	0.9594

TABLE II: The k, α coefficients at $f = 38$ GHz

DSD	k_H	α_H	k_V	α_V
Marshall-Palmer	0.2826	0.9891	0.2645	0.9747
Gamma, $\mu = -3$	0.2891	0.9018	0.2689	0.8817
Gamma, $\mu = -2$	0.2941	0.9161	0.2742	0.8960
Gamma, $\mu = -1$	0.2935	0.9473	0.2738	0.9299
Gamma, $\mu = 0$	0.2893	0.9772	0.2698	0.9627
Gamma, $\mu = 1$	0.2849	0.9991	0.2657	0.9867
Gamma, $\mu = 2$	0.2811	1.0138	0.2623	1.0030
Gamma, $\mu = 3$	0.2756	1.0245	0.2569	1.0149
ITU-R 838-3	0.4001	0.8816	0.3986	0.8607

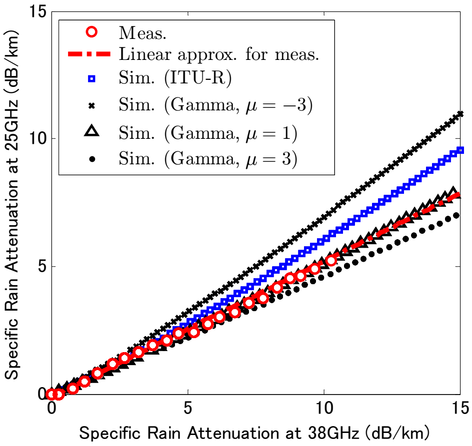

Fig. 3: Frequency scaling of specific attenuation of Link 3 (Moderate rain event on December 12^{nd}, 2010).

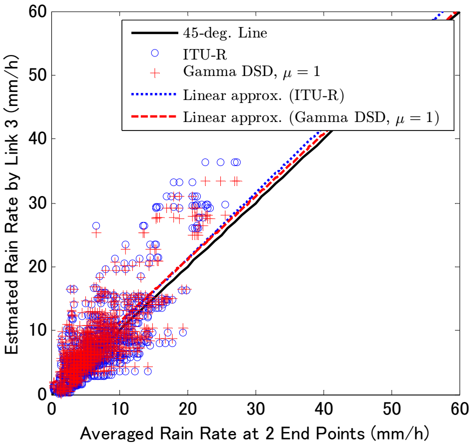

Fig. 4: Estimated rain rate using rain attenuation of Link 3 at 38 GHz (Moderate rain event on December 12^{nd}, 2010).

algorithm can be summarized as follows

- The measured specific attenuations γ at 25 and 38 GHz are used to plot frequency scaling as shown in Fig. 3.
- In the simulations, the coefficients k and α from Tables 1 and 2 as a look-up database for given DSD are used for simulating the specific rain attenuations at 25 and 38 GHz. Then, the simulated frequency scaling of all DSDs are plotted in the same figure.
- At each time-step, the algorithm determines the most probable value of DSD which are common for the two frequencies in the sense of the RMS obtained by the simulation and measured frequency scaling. Fig. 3 shows the simulation with ITU-R, gamma DSDs of $\mu = -3, 1, 3,$ and measured frequency scaling. In this rainfall event, the best-fit DSD is gamma DSD with $\mu = 1$.
- Then, these coefficients with the smallest RMS are used for estimating the rain rates.

A software is developed for the practical implementation using the rainfall estimation technique. Fig. 4 shows the estimated rain rate using attenuation of Link 3 during the moderate rain event occurred on December 12^{nd}, 2010, compared with averaged rain rate at the two end points (A and F) of Link 3 at 38 GHz. For comparison, the estimation of rain rate using ITU-R coefficients is also plotted, in blue. It can be observed that during light rain, the estimated rain rates using the proposed method are very similar using both sets of coefficients. However, at the higher precipitation rates, the estimated rain rates from dual-frequency measurements are superior to those obtained using the ITU-R coefficients. The results suggest that variations in the DSD are more significant at higher rain rates.

IV. CONCLUSION

In this paper, a deterministic algorithm was presented for sensing rainfalls. An estimation technique of rain rate considering the effects of DSDs has been proposed. The method was verified on a rain event in Tokyo and the results indicated that millimeter-wave can be successfully used for local weather monitoring, tracking the rainfall in real-time. For the future, a deterministic algorithm for early predicting rainfall rates from past data will be proposed.

ACKNOWLEDGMENT

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REFERENCES

[1] J. A. Wells, “Faster than fiber: the future of multi-Gb/s wireless,” IEEE Microwave Mag., vol. 10, no. 3, pp. 104-112, 2009.
[2] H. V. Le et al., “Millimeter-wave propagation characteristics and localized rain effects in a small-scale university campus network in Tokyo,” IEICE Trans. Commun., vol. E97-B, no. 5, pp. 1012-1021, May 2014.
[3] R. Nebuloni, C. Capsoni, “Effect of hydrometeor scattering on optical wave propagation through the atmosphere,” EuCAP2011, Italy, Apr. 2011.